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TECHNICAL OPERATIONS SUPPORT (TOPS) II

Delivery Order 0011: Summary Status of MISSE-1 and MISSE-2 Experiments and Details of Estimated Environmental Exposures for MISSE-1 and MISSE-2

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The purpose of this report is to provide a description of the exposure conditions experienced by the hardware and materials specimens from the MISSE-1 (Materials International Space Station Experiment) and MISSE-2 space flight experiments. Figure 1 shows an image of MISSE-1 and MISSE-2 deployed on ISS. The nominal ram-facing sides of each experiment are visible in this image. Quantitative values are provided when possible for selected environmental factors. There are still a number of measurements that need to be complete, details of background contamination levels to be determined, and perhaps additional consideration of the effects of secondary scattering of atomic oxygen, but it is not likely that the overall conclusions and observations in this report will change significantly.

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1.0 Introduction

The purpose of this report is to provide a description of the exposure conditions experienced by the hardware and materials specimens from the MISSE-1 (Materials International Space Station Experiment) and MISSE-2 space flight experiments. Figure 1 shows an image of MISSE-1 and MISSE-2 deployed on ISS. The nominal ram-facing sides of each experiment are visible in this image. Quantitative values are provided when possible for selected environmental factors. There are still a number of measurements that need to be completed, details of background contamination levels to be determined, and perhaps additional consideration of the effects of secondary scattering of atomic oxygen, but it is not likely that the overall conclusions and observations in this report will change significantly.

Many people contributed significant measurements, model predictions, and analyses used in this report. Several sections were originally written by different authors. For those sections, the name of the author is listed with the section title. The meteoroid and debris counts were conducted by Miria Finckenor (NASA MSFC), William Kinard (NASA LaRC), Kim DeGroh and Joyce Dever (NASA GRC) and Dr. Suzanne Woll (United Technologies Research Center. Russell Graves (Boeing) provided the impact modeling calculation for comparison with the observed impact distribution. Atomic oxygen recession measurements for selected materials were conducted by Miria Finckenor, Kim DeGroh and Joyce Dever (NASA GRC), Dr. Richard Kiefer (College of William & Mary), and Dr. Suraj Rawal and Alan Perry (Lockheed-Martin), and shared to support the atomic oxygen fluence estimates cited in this report. Karen Gibson (NASA LaRC) provided a summary description of the oxidation observed on the underside of the tray base plates. Dr. Eugene Normand (Boeing) and George Perry (Boeing) provided the assessments of the radiation exposure levels as measured using thermoluminescent detectors. Visual inspections under ambient and "black-light" at NASA LaRC, together with optical measurements on selected specimens by Miria Finckenor, was the basis for the initial contamination level assessment. Gale Harvey and John Chapman (NASA LaRC) provided the on-orbit thermal data. A thorough analysis of the thermal data, written by Dr. John Lawler (ATEC, Inc.), is included within this report. Dr. Carlos Soares (Boeing) provided detailed models of the view factors from the each side of MISSE-1 and MISSE-2, to aid our assessment of shielding effects on each surface.

Both modeling techniques and a variety of measurements and observations were used to characterize the environmental conditions experienced by the specimens flown on the MISSE-1 and -2 flight experiments. There experiments were deployed at different locations on the ISS airlock August 16, 2001, and were retrieved July 30, 2005. The altitude and solar cycle variations are shown in figures 2 and 3, respectively. The attitude changes of ISS over the time period of the MISSE experiments is shown in appendix A. Appendix B shows a set of images that represents the post-flight disassembly of the experiments.

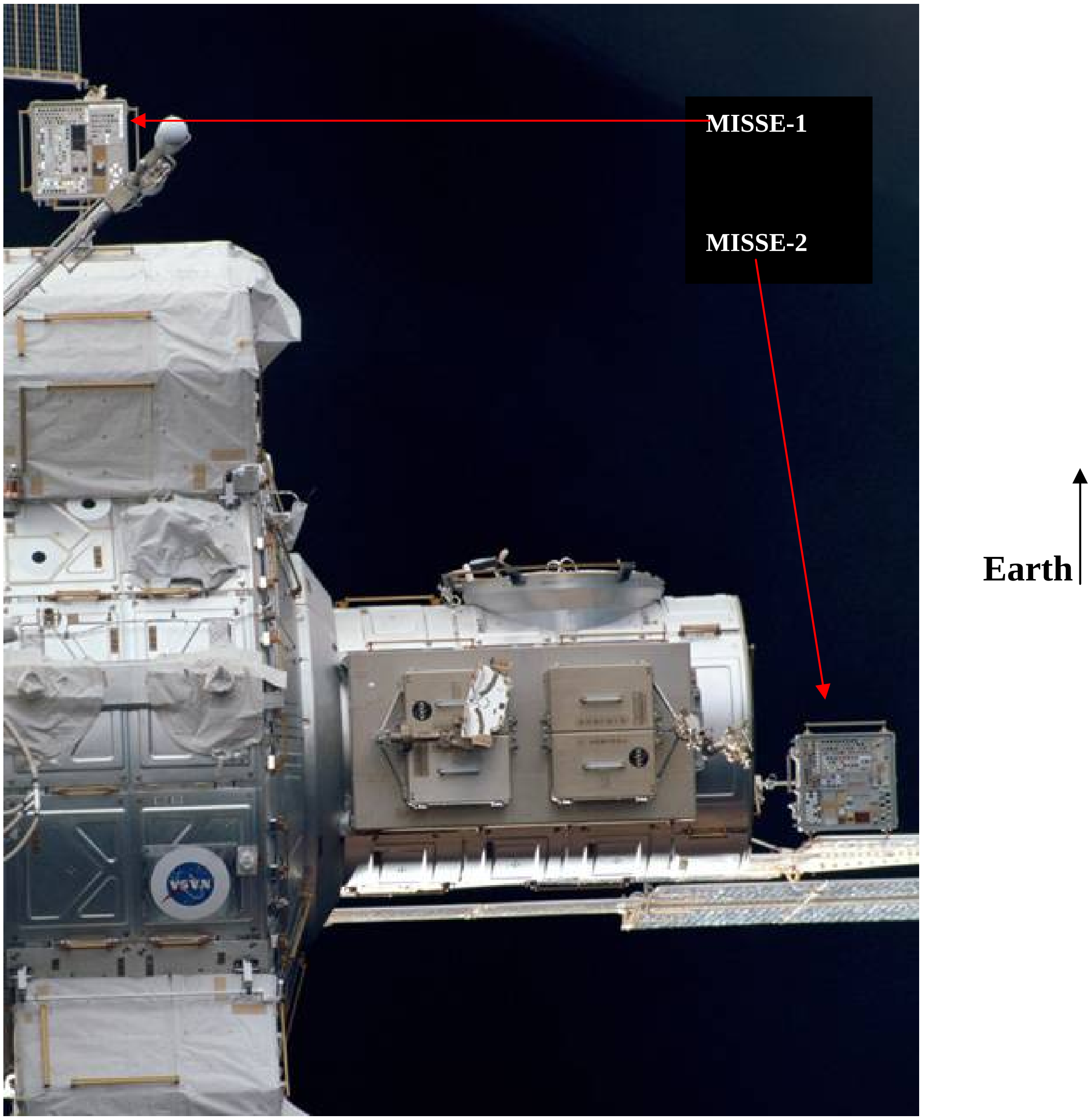

Figure 1 MISSE-1 and MISSE-2 mounted on the ISS airlock. Nominal "Ram-facing" sides are visible (NASA Image)

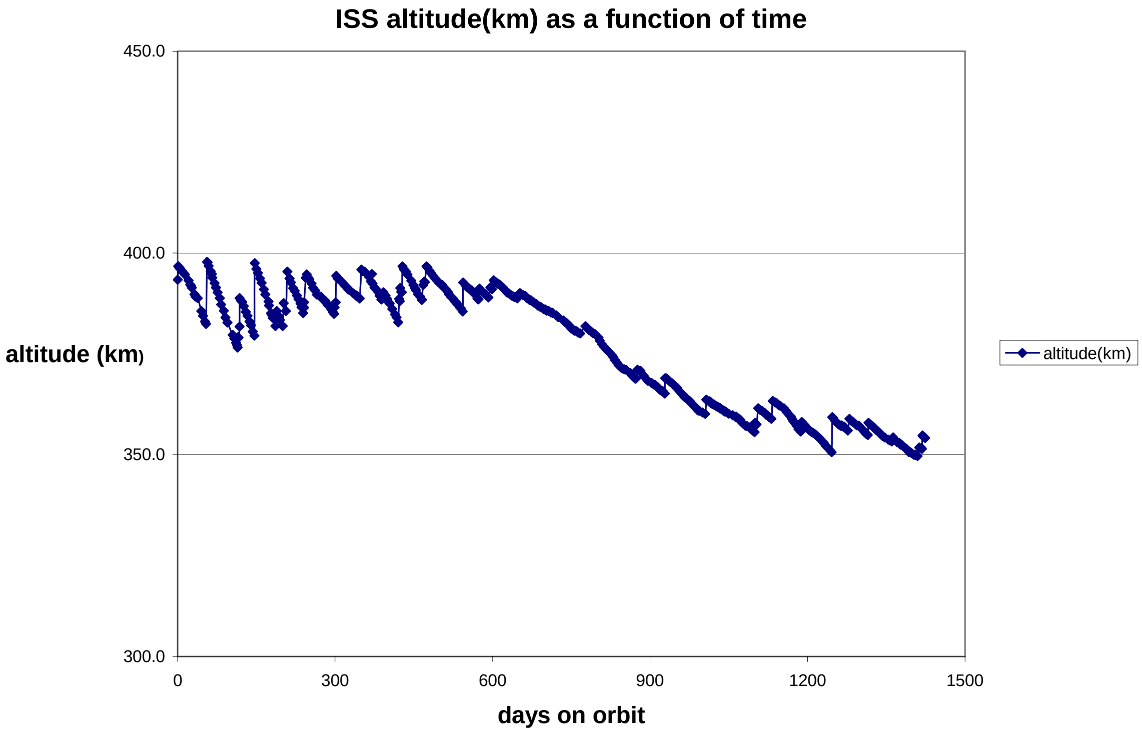

Figure 2 Variation in altitude of ISS over time

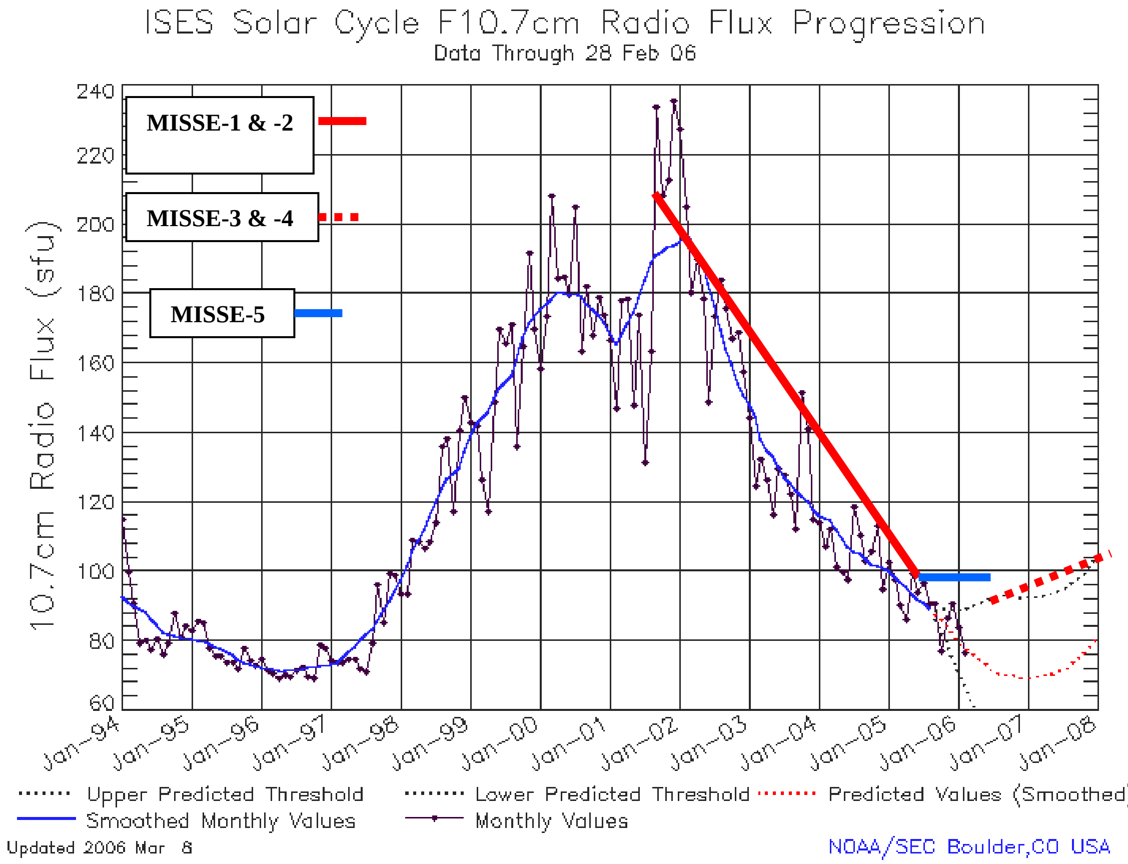

Figure 3 Variation in solar activity over a solar cycle, as represented by 10.7 cm flux ground measurements

2.0 Summary Status of experiments

During the 2006 National Space and Missile Materials Symposium, June 26-30, 2006, there were 6 overview, 18 detailed technical, and 4 poster presentations, specifically concerned with MISSE-1 & -2. This was part of a series of 37 talks and 10 poster presentations related to LEO flight experiments, including the MISSE series of flight experiments, and effects of space environments on materials. A detailed Symposium Proceedings will be published. A significant number of experimenters have not completed analysis of their MISSE-1 and -2 specimens to date. A number of specimens were severely degraded, and in certain instances, completely destroyed, due to the extended exposure time. The increased solar exposure was useful to many specimens where the primary interest is performance lifetime under solar exposure. Thermal control materials, solar array hardware, optical materials, benefited in particular. Appendix B contains a selection of post-flight images taken during the disassembly of MISSE-1 & -2 at NASA LaRC in late 2005.

3.0 Atomic Oxygen Fluences

The fluence of atomic oxygen was estimated using a detailed predictive model that accounted for altitude, ISS attitude changes, thermal velocity spreading in the ambient atmosphere, co-rotation of the atmosphere, and oxygen atom number density variation with solar activity. Measurements of Kapton recession were also used to determine atomic oxygen fluence for all surfaces of the MISSE-1 and MISSE-2 experiments.

Kapton is used to determine fluence because the recession rate of Kapton is well known from previous flight experiments. This material is widely used on spacecraft and acts as a kind of “internal standard” for correlating the exposure on one experiment with another. Because of the long-term exposure period on these experiments, the recession of silver-backed FEP Teflon (Ag/FEP) may also provide a reasonable estimate of the total fluence. Measured mass loss and thickness decrease for Kapton and Ag/FEP specimens indicate the atomic oxygen fluence on the “Ram-facing” side of MISSE-2 to be between ~6.5 x 10^{+21} and 9.1 x 10^{+21} atoms/cm^2, depending on the specific location on the MISSE-2 tray. This significant variation is due to shielding effects due to the airlock structure. The lower value is for specimens near the edge of the PEC closest to the attach point on the airlock, while the larges fluence value is for specimens close to the edge of the PEC at the greatest distance from the airlock structure.

Results of the initial modeling calculations are shown in figures 4 and 5 and Table 1. The atomic oxygen modeling to date has not accounted for possible shielding by nearby structural elements, therefore the values reported from the model predictions are "maximum possible" values. Figure 4 shows a plot of atomic oxygen fluence as a function of time in orbit for the nominal ram-facing side of MISSE-1 and MISSE-2. Figure 4 also shows the predicted fluence for the nominal wake sides of MISSE-1 and MISSE-2. Measurements of recession of Kapton specimens on the MISSE-1 wake side indicates an estimated fluence of 1.1-1.35 x 10^{+20} atoms/cm^2, an order of magnitude less than the value estimated using the model. This demonstrates that shielding by elements of the ISS structure was significant for MISSE-1.

During periods of time when a Space Shuttle was docked to ISS, the Space Shuttle structure blocked the ram side of MISSE-1 from receiving any atomic oxygen. MISSE-2 was still exposed to atomic oxygen flux during these time periods, leading to the ~5% difference in calculated fluence for the nominal "ram" sides of the two experiment packages indicated in table 1. During periods of time when the ISS was in an orientation such that the nominal wake side of the MISSE-2 experiment was actually facing the ram direction, the MISSE-2 experiment was (mostly) blocked from exposure to atomic oxygen by a bank of Russian solar arrays. Assumption of 100% shielding by the Russian solar arrays leads to an atomic oxygen fluence estimate that is an order of magnitude too low.

Measurement of recession of a polyimide flown on the nominal wake side of MISSE-2 confirms the effectiveness of the shielding. The measured exposure value is just over 1% of the maximum possible exposure calculated using the Boeing computer model.

MISSE-1 was not generally shielded by these arrays. However, the measured exposure value for the nominal wake side of MISSE-1 is only ~10% of the maximum possible exposure calculated using the Boeing computer model. This indicates that other portions of the ISS structure provided significant shielding during times when the "wake" side was potentially exposed to atomic oxygen

The shielding of MISSE-2 "UV-side" by the solar arrays means that changes observed after the 4-year exposure are due primarily to solar UV exposure of the material. The atomic oxygen fluence was less than received on typical Space Shuttle short-term materials experiments.

Figure 5 shows that the exposure of the "wake" side to atomic oxygen occurred as several distinct, short periods of time. There are really five time periods during which the exposures occurred. The last period is two separate parts, with one contribution significantly larger than the other.

The Space Shuttle docking periods are listed in table 1.

STS 105 (MISSE deployment, August 16) – August 20, 2001
STS 108 December 7 – December 15, 2001
STS 110 April 8 – April 19, 2002
STS 111 June 5 – June 19, 2002
STS 112 October 7 – October 16, 2002
STS 113 November 23 – December 7, 2002
STS 117 January 16 – January 31, 2003
STS 114 July 28 – (MISSE retrieval, July 300, 2005)

Table 1 Time periods during MISSE exposure when an STS was docked to the ISS

In summary, the "ram" surface predictions from the models are relatively close to the measured values (10-25% different). The exposure predictions for the "wake" surfaces are roughly off by an order of magnitude. The results also indicate that the Russian solar arrays only partially shield the "wake" side of MISSE-2 during times when the ISS was turned essentially "end for end." To quantify this further would require an expensive calculation with significant structural fidelity in the model. Estimates of recession of other materials on the "wake-facing" surfaces should rely on fluences determined from the measured values of polyimide materials on these surfaces.

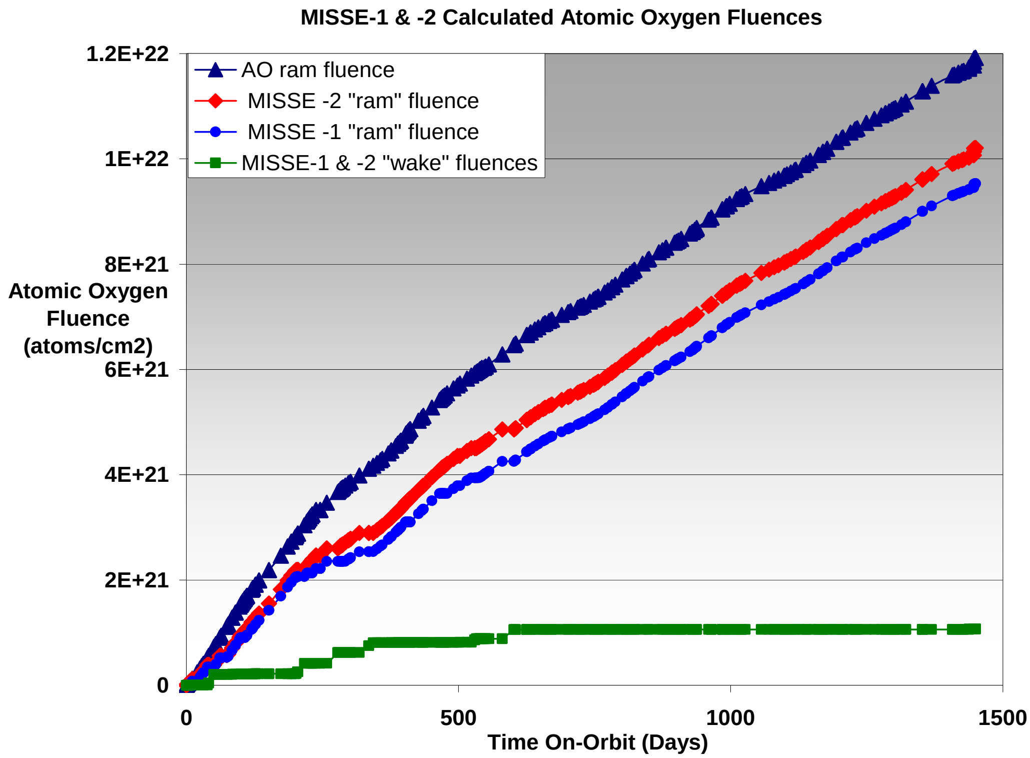

Figure 4 Nominal Calculated Atomic Oxygen fluences for MISSE-1 and MISSE-2

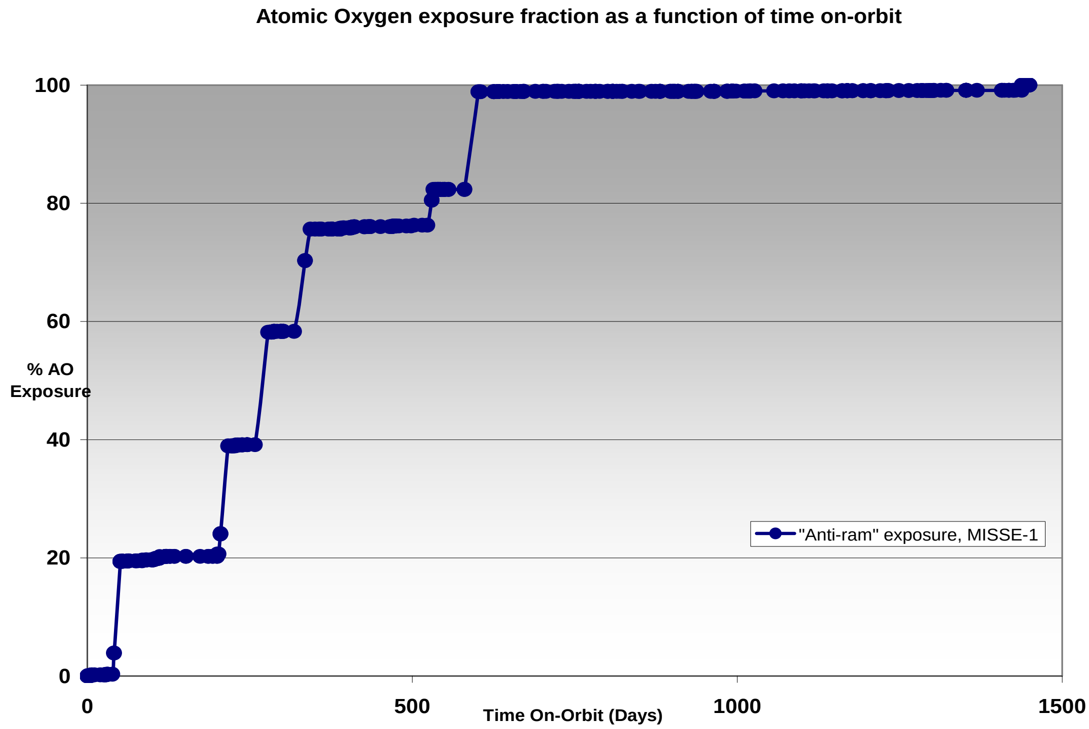

Figure 5 Nominal fraction of atomic oxygen fluences for "anti-ram" side of MISSE-1 as a function of time

Table 2 shows the measured and calculated fluence for each side of the MISSE-1 and -2 containers. The calculated values for the ram values take into account shielding by the STS when docked to ISS, but take no account of any other nearby structure. The measured values are from polyimide specimens with some material remaining in the exposed areas at the end of the flight. At certain locations, 5 mil thick Kapton specimens were completely eroded. To remove 5 mils of Kapton requires an atomic oxygen fluence of at least 4.2 E+21 atoms/cm^2, based on the accepted recession rate of 3.0E-24cm3/atom for Kapton.

The calculated values for the MISSE-2 wake fluence assumes 100% shielding by the Functional Cargo Block solar arrays. The correction for the shielding on the MISSE-2 wake side by the arrays does not lead to agreement between the calculated and measured values.
For the MISSE-1 wake surface, the agreement between calculation and measurement is also not good. No account of nearby structure is considered in the MISSE-1 wake calculations.

Location	Measured fluence (atoms/cm^2)	Calculated fluence (atoms/cm^2)
MISSE-1, ram	-	9.5 E+21
MISSE-1, wake, third value from opposite edge of first two	1.1 E+20,1.15E+20, 1.35E+20	1.06 E+21
MISSE-2, ram, near airlock	6.5 E+21, 6.8 E+21	9.9 E+21
MISSE-2, ram, away from airlock	8.5 E+21, 9.1 E+21	9.9 E+21
MISSE-2, wake	1.67 E+20, 1.99E+20	2.5E+19

Table 2 Measured and calculated atomic oxygen fluence, MISSE-1 and MISSE-2

Visual observations were made on the nuts and nutplates located on underside of the PEC trays and on the inside of the PECs. A summary of observations of evidence of oxidation on MISSE 1 & 2 during the initial post-flight inspections, Oct. 11, 2005 are described below. Figure 6 shows the underside of one of the baseplates, with the oxidation of the silver-coated nutplates clearly visible. Oxidation observed on the underside of each baseplate was due to indirectly scattered atomic oxygen. The ~1/8" gap between the baseplate and the interior wall of the PEC allowed atomic oxygen access to the baseplate underside.

3.1 MISSE PEC 1 (bent stem)

<u>AO-UV Side (PEC side w/ handrails)</u>

The MISSE-1 AO-UV side tray bottom nutplates and nuts appear evenly oxidized to a dull black powdery finish. Minimal to no flaking of oxidation is observed.

For the PEC interior, nuts at the bottom vent are oxidized to black with minimal flaking. Nuts and nutplates on the PEC sides have oxidization ranging from a light dull gray to almost full black finish. Minimal to no flaking of oxidized material is observed.

<u>UV Side (PEC side w/ stem)</u>

The MISSE-1 UV side tray bottom nutplates and nuts on the bottom tray are uniformly oxidized with a dull black powdery substance. The location on the tray does not appear to matter. The threaded area of the nut plates that had fasteners installed were clean and free of oxidation. The threaded area of nutplates that did not have fasteners installed had oxidation on the threaded area.

For the PEC interior, all nutplates and nuts on the under side of the PEC are all uniformly oxidized with a dull black powdery substance. The location within the PEC does not appear to matter.

3.2 MISSE PEC 2 (straight stem)

AO-UV Side (PEC side w/ handrails):

For the AO-UV side of MISSE-2, the nutplates and nuts on the under side of the tray appear evenly oxidized to a dull black powdery finish.

For the PEC interior, the nuts appear to be more oxidized on the end closer to the ISS (stem end of PEC)

UV Side (PEC side w/ stem)

For the UV side tray bottom, the nutplates on the end closer to the PEC stem (closer to ISS) are more oxidized than nutplates further from the PEC stem. Thick dark black oxidation with a lot of flaking on nutplates was observed on the stem side. Grayish black oxidation with minimal to no flaking was observed on the hinge end of this PEC.

For the PEC interior, the bottom vent nutplates toward the stem are darker than the vent nutplates towards the hinge. Side nutplates are more oxidized than nuts. Oxidization on nuts appears uniform, not depending on the location on PEC sides.

Figure 6 Post-flight image of underside of baseplate showing oxidation on the silver-coated nut plates (NASA Image)

4.0 Solar Exposure Levels

Both calculations using computer models and measurements of solar UV dose were carried out for MISSE-1 and MISSE-2. Photo-diodes were placed on both sides of each of the MISSE-1 and MISSE-2 experiments. The current from a photodiode drove a coulombmeter to deposit material on an electrode. Ground calibration of these devices showed a capability to monitor up to a maximum of ~1400 equivalent sun hours (ESH). The coulombmeters were determined to be saturated upon post-flight evaluation.

Calculations were made to determine the ESH of exposure on both PECs. These calculations included both direct and Earth-reflected solar radiation. The spectrum of Earth reflection solar radiation has a reduced contribution from the vacuum UV portion of the spectrum due to absorption by the Earth's atmosphere. Table 3 shows the range of solar exposure levels across each experiment surface.

Experiment	Nominal Exposure	Range of ESH(total)	Earth-reflected ESH
MISSE-1	AO-UV	5400-6400	930-1200
MISSE-1	UV	4500-5600	700-800
MISSE-2	AO-UV	5000-6700	650-820
MISSE-2	UV	4800-6200	700-800

Table 3 Solar exposure levels on each experiment surface

The calculations are Monte-Carlo determinations and have inherent uncertainties that are the square root of the ESH values reported. Given the limitations on the fidelity of the representation of the ISS structure used in calculations, the uncertainty in the absolute values is probably at least 10%. Figures 7 through 10 show the nominal ESH values for each MISSE-1 and -2 surface as a function of location. The calculations were carried out using a grid of 2 inch by 2 inch squares. The relative variation across the "atomic-oxygen-facing" side of MISSE-2 is the greatest among the 4 surfaces. The "UV-facing" sides have slightly lower ESH values due primarily to the fact that these surfaces had a larger view factor to the ISS. The essential point of the ESH values is that at these exposure levels, the solar-induced changes for most materials should have reached saturation. Optical changes for specimens on the UV-facing surfaces should represent "end-of-life" values for even longer missions. Well over half the ESH of solar exposure was received subsequent to virtually all (99%) of the atomic oxygen exposure.

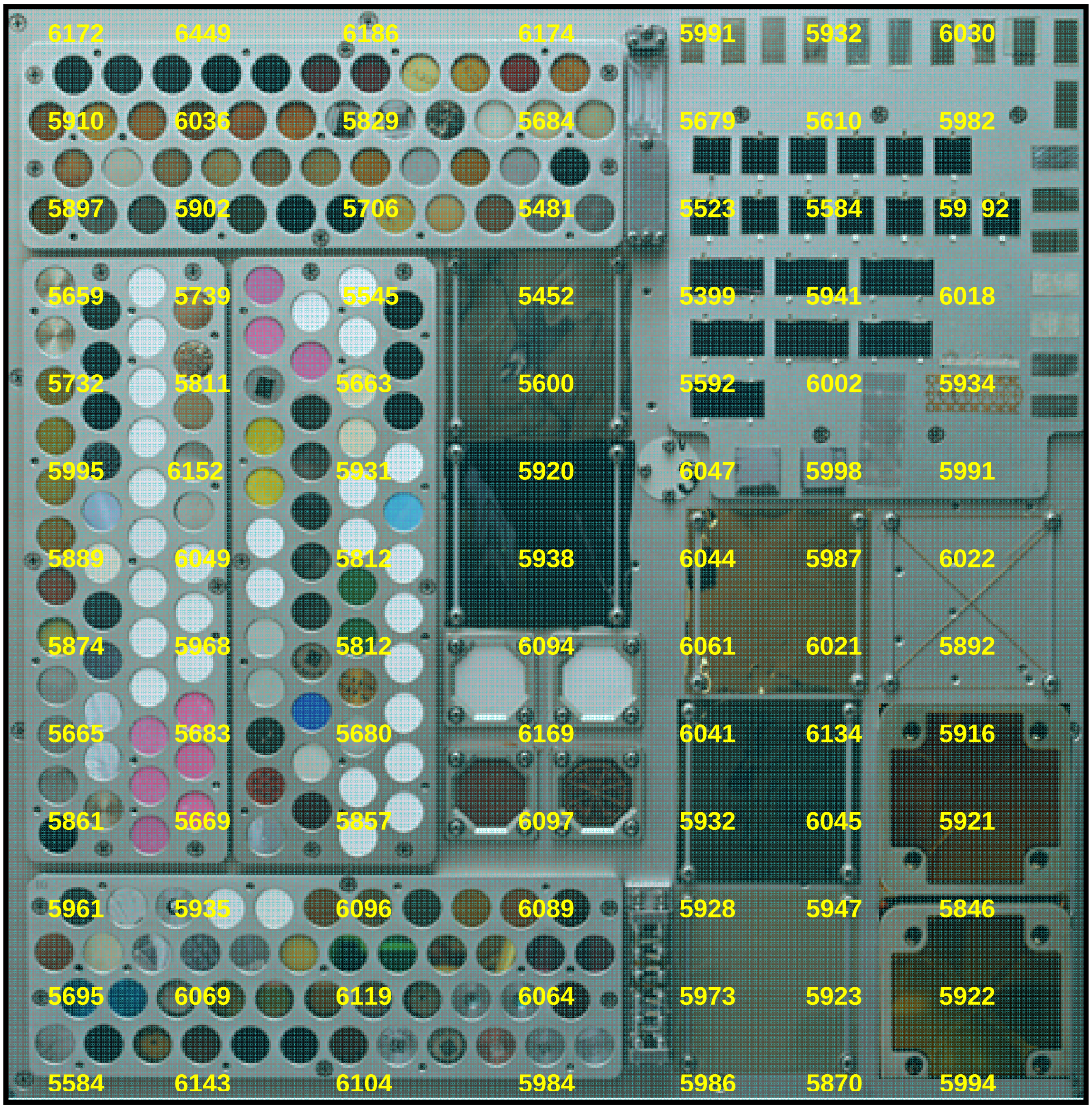

Figure 7 MISSE-1 AO/UV side total Equivalent Sun Hours of Exposure (NASA pre-flight image)

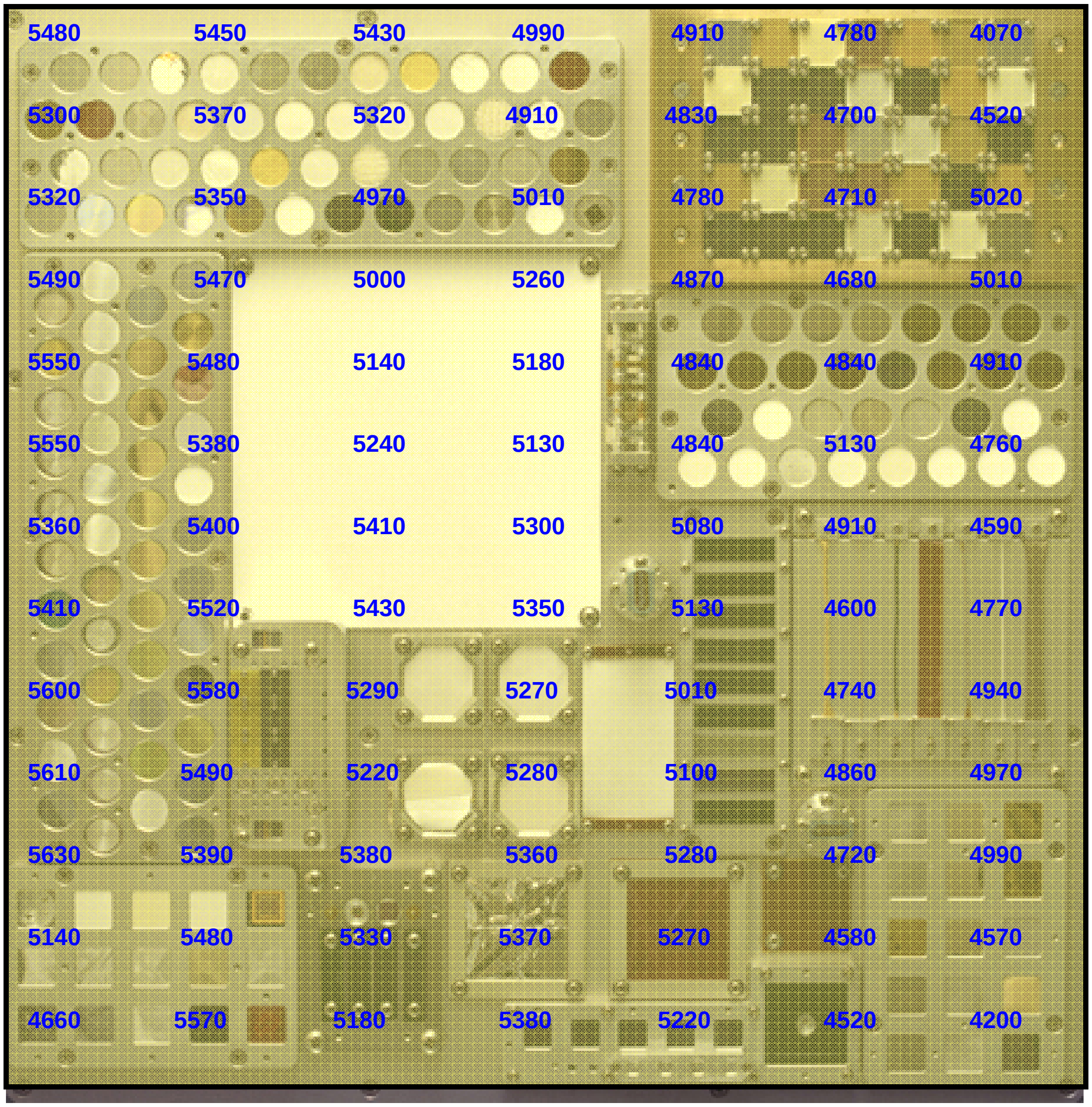

Figure 8 MISSE-1 UV side total Equivalent Sun Hours of Exposure (NASA pre-flight image)

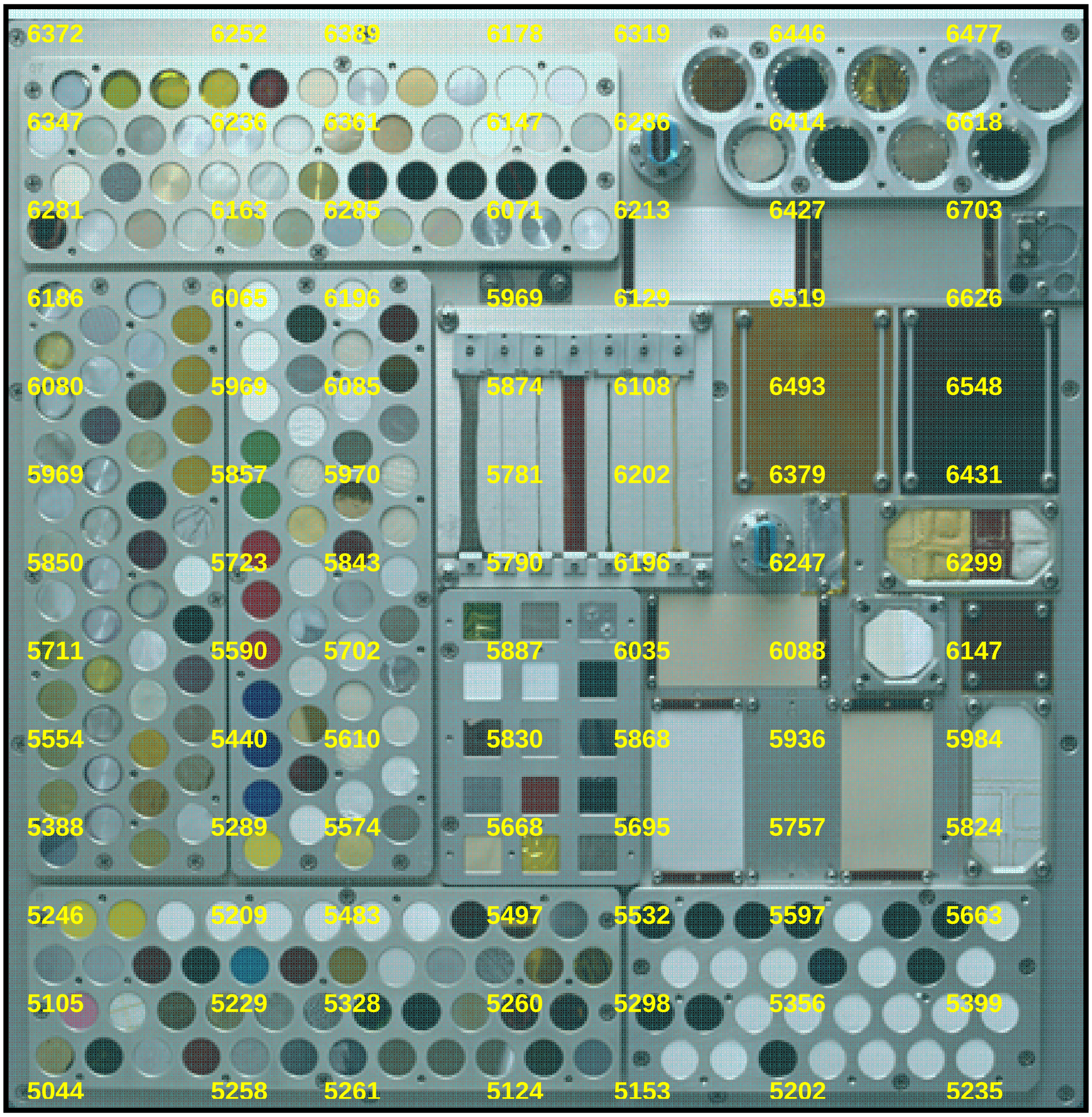

Figure 9 MISSE-2, AO/UV side total Equivalent Sun Hours of Exposure (NASA pre-flight image)

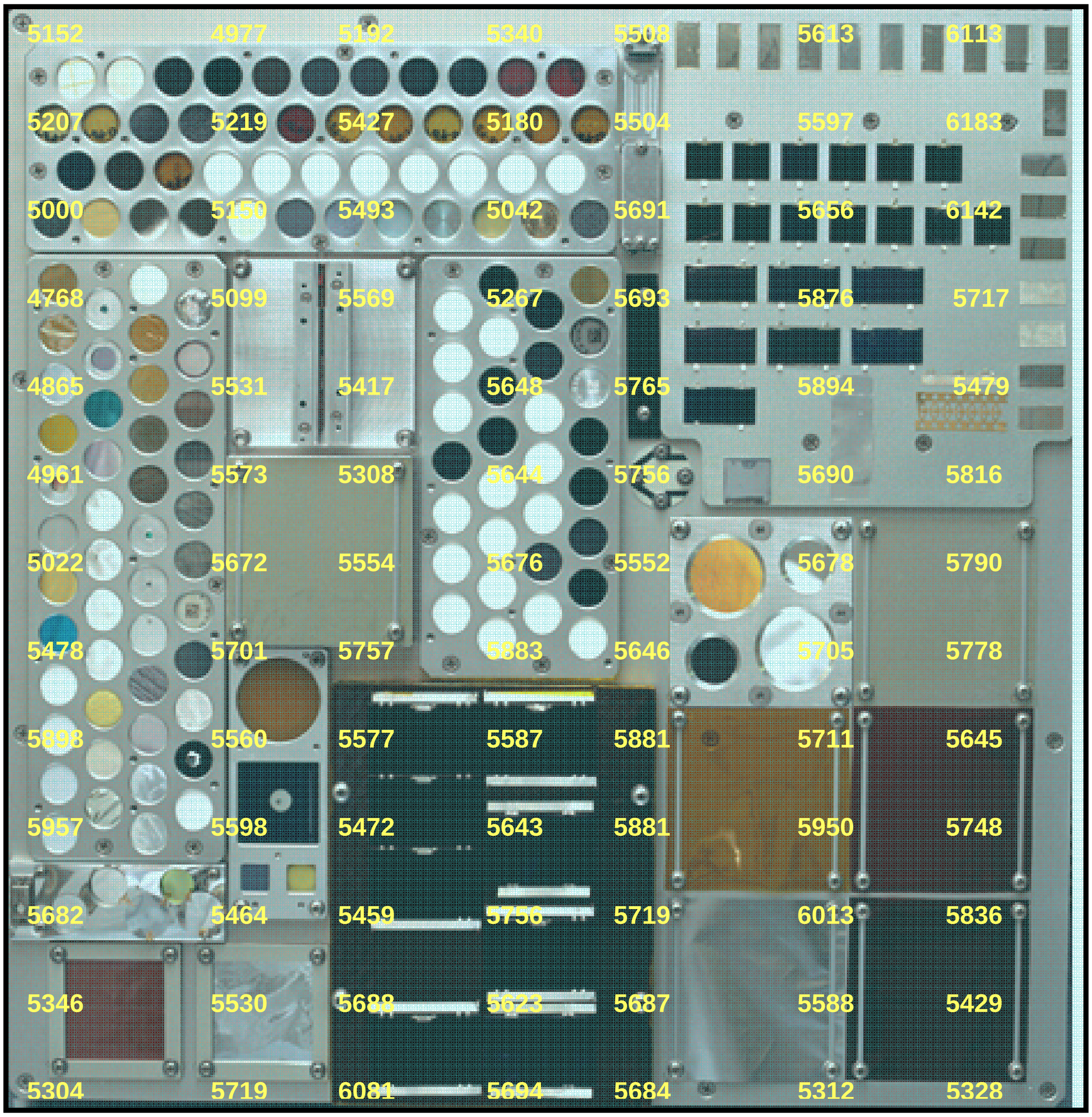

Figure 10 MISSE-2, UV side total Equivalent Sun Hours of Exposure. (NASA pre-flight image)

5.0 Thermal Cycling

Measurements of temperature over the entire flight duration were taken using Veriteq data loggers. Due to the unanticipated length of the flight, the data storage capacity of the Dataloggers was exceeded and the temperature history for almost the first two years was overwritten. The data for the final two years was captured and read out subsequent to the return of the hardware. Figure 11 shows a thermal history as represented by temperatures measured by taping a thermocouple to the base plate, roughly in the center of a baseplate. The data to the right clearly shows the warmer temperatures experienced post-flight (the ~70^{o}C temperatures without the extreme thermal cycling).

Most thermal cycles were between about +40C and -30C, with occasional short-term excursions to more extreme temperatures. The data loggers were rated to perform between +85 and -40C and they worked well.

The average, minimum, and maximum temperatures in each of the four data sets are shown below in table 4. The correlation of data set numbers with specific baseplates is also defined. MISSE-1 was slightly colder on average, than MISSE-2. This difference may be due to the slightly decreased amounts of solar exposure on MISSE-1. MISSE-1 is closer to the main axis of ISS, and is more shielded by the ISS structure than MISSE-2. For both MISSE-1 and MISSE-2, each nominal ram-facing side is colder on average than each corresponding wake-facing side. This is likely due to the greater view factor to space for each ram-facing surface. The bulk of the ISS structure is toward the wake-facing direction for these experiments.

Data Set	Experiment/ Exposure	Average Temperature (°C)	Minimum Temperature (°C)	Maximum Temperature (°C)
71147	MISSE-1 AO	-13.6	-59.6	38.4
71154	MISSE-1 UV	-13.3	-53.8	66.3
71157	MISSE-2 AO	-2.7	-44.7	31.6
71017	MISSE-2 UV	16.7	-45.9	65.1

Table 4 Average, Minimum, and Maximum Temperatures in Four MISSE PEC Thermocouple Data Sets

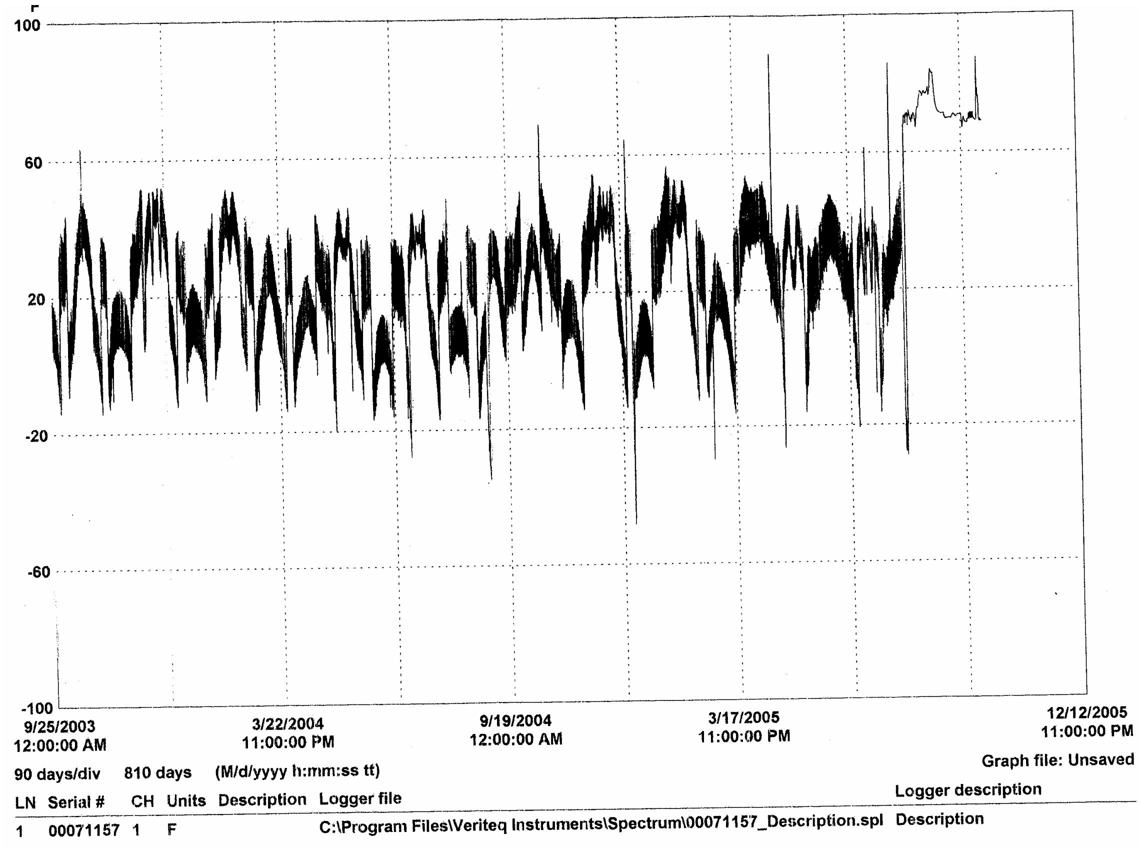

Figure 11 Thermal history of MISSE experiments

6.0 Detailed analysis of the Temperature History of MISSE-1 & -2 (Dr. John Lawler)

NASA-Langley supplied four sets of temperature readings from MISSE-1 and MISSE-2 to Dr. John Lawler of ATEC, Inc., who conducted the following thermal analysis.

The temperature data sets contain about 70K per channel, with a data point collected every 15 minutes over a period of about two years. For ease of analysis, the datasets were separated by calendar years.

There was one thermocouple attached to each of the two baseplates on MISSE-1 and MISSE-2. The temperature histories from all four data loggers are presented below. In order to make the temperatures easier to read over long periods, most of the data on the graphs below are averages of 32 consecutive temperature readings. Figure 12 shows both the complete temperature data and the 32-point averages. The short term variation around these 32-point averages is generally ±10°C.

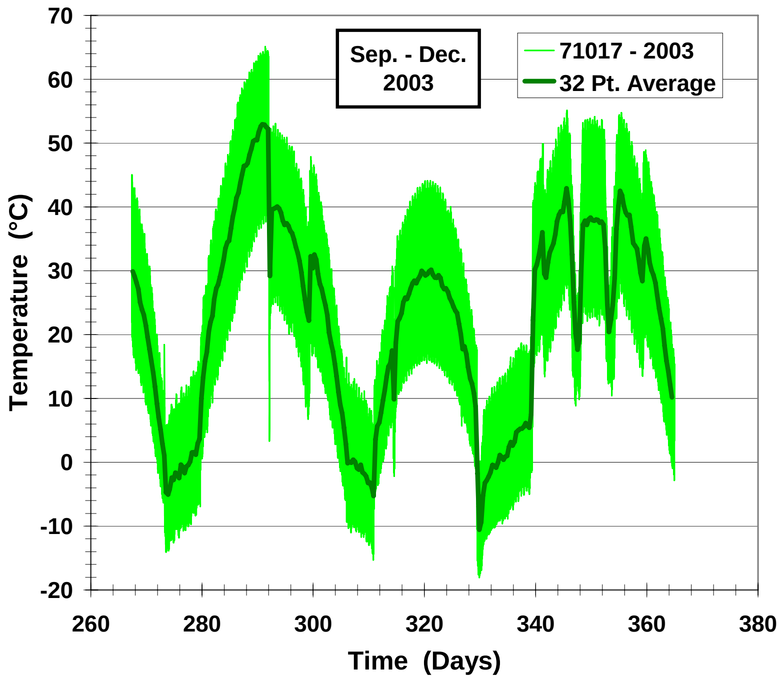

Figure 12 Time-temperature history of MISSE-1 & -2 data loggers

In figure 13, the time scale has been expanded and a sine wave has been fit to the temperature readings shown. The best-fit frequency is about 92 minutes, which is the nominal orbiting period of the International Space Station. Again, the ±10°C variation in temperature over each orbit is shown by this graph.

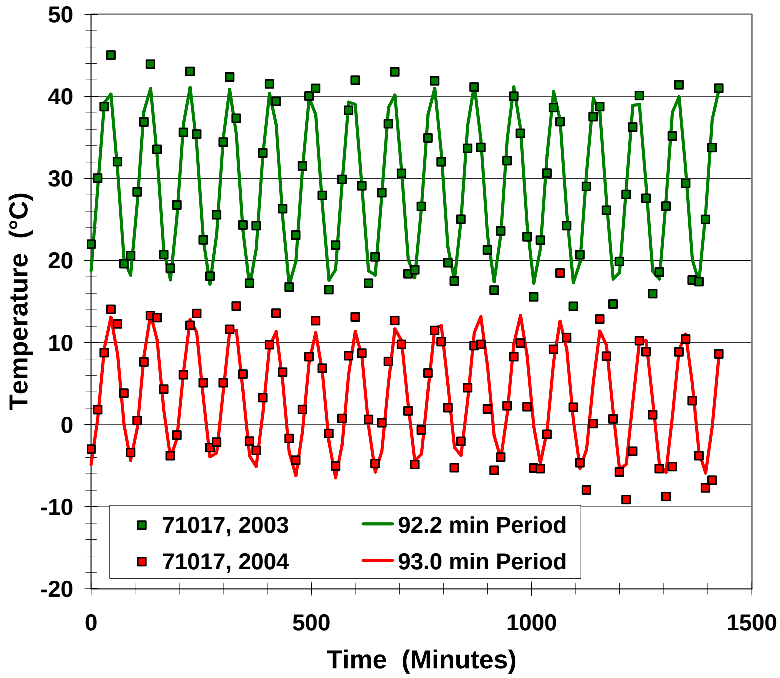

Figure 13 Short-term orbital temperature variations

The complete data sets of the average temperatures are shown in Figures 14-17. Each year is a different color. The x-axis is calendar days from the beginning of the year. In many of the data sets, a larger scale fluctuation can be discerned that coincides with the lunar orbiting period of about 28 days. These fluctuations shift by about 10 days in one year to the next, which is consistent with the difference between an Earth year and 12 lunar cycles. Although in some portions of the data sets, a year-to-year pattern does not exist.

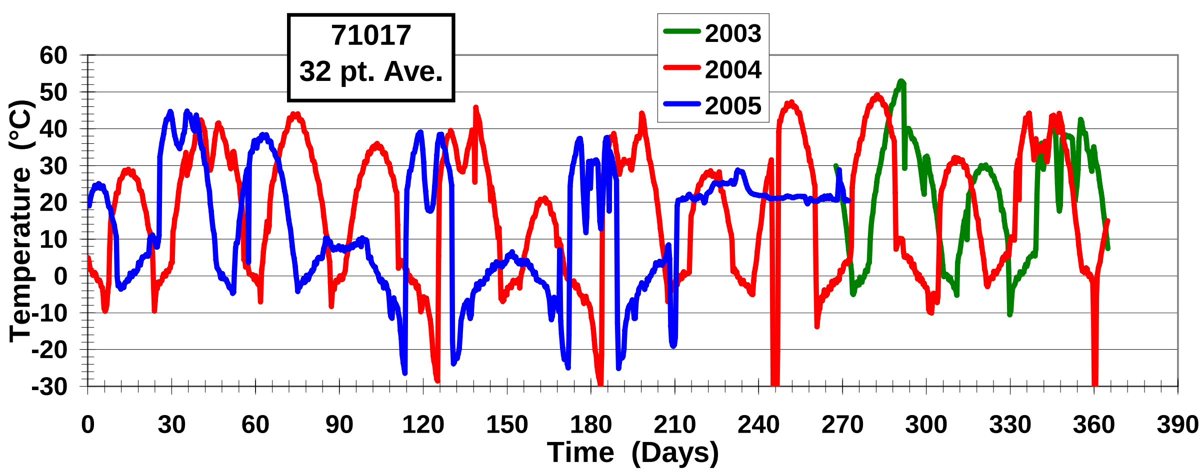

Figure 14 Average temperatures for datalogger 71017

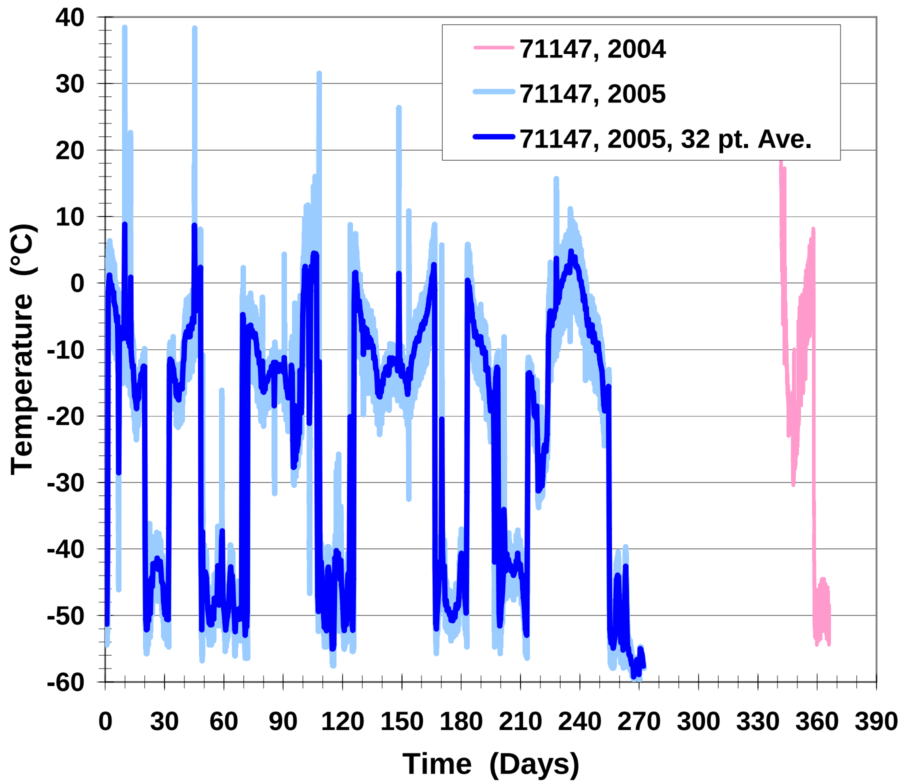

Figure 15 Average temperatures for datalogger 71147

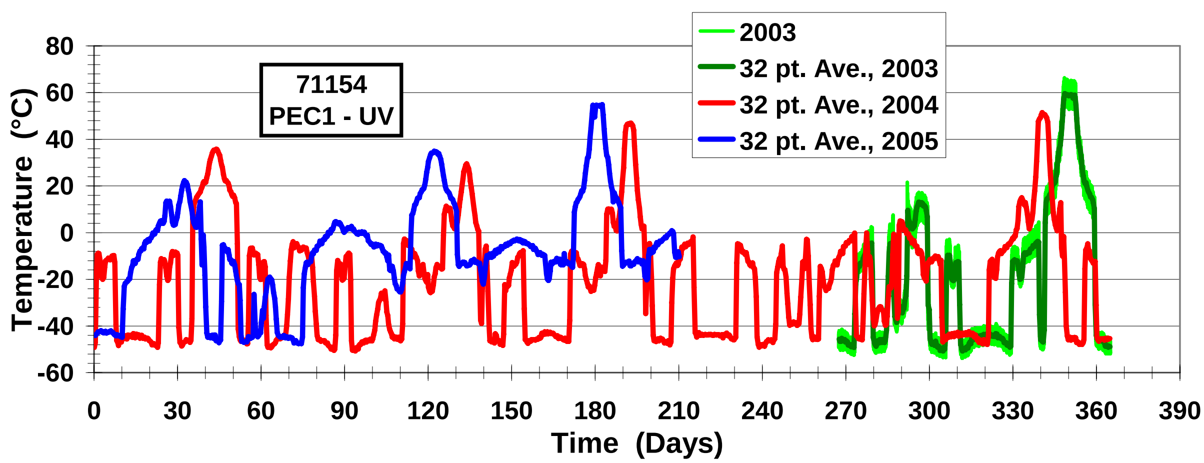

Figure 16 MISSE-1 UV-side, Average temperatures for datalogger 71154

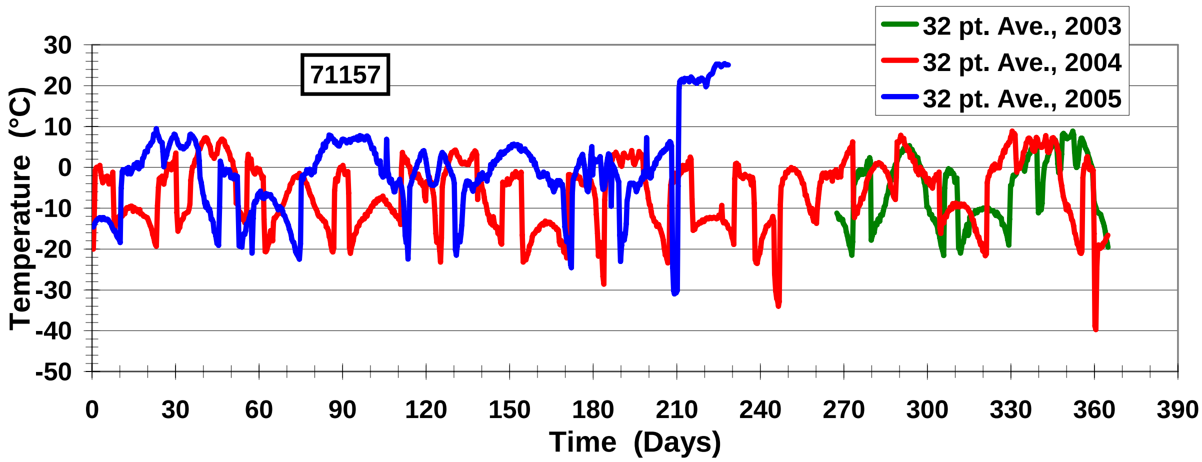

Figure 17 Average temperatures for datalogger 71157

Temperature Extremes Occurring during MISSE-1 & -2

As shown below in figures 18 and 19, the temperatures of PEC-1 were close to -50°C for 15 to 20 days several times during its deployment. The duration of these cold temperatures may be an issue for the active experiments being developed for MISSE-6. PEC-2 experienced significantly milder temperatures with regard to low temperature exposure. The maximum temperatures of the UV sides of the PECs were about 30°C higher than the AO side (about 65°C versus about 35°C).

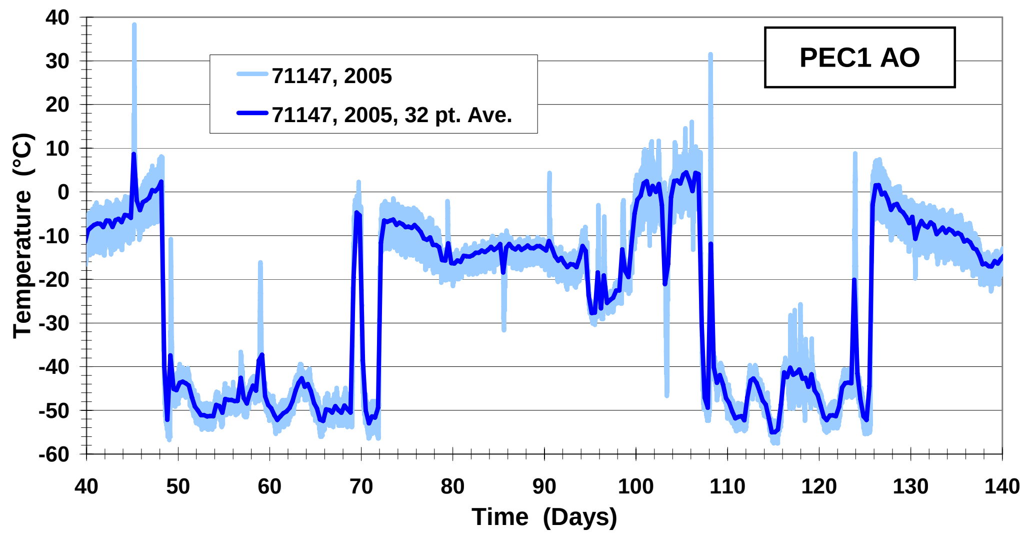

Figure 18 Temperature extremes recorded n datalogger 71147, MISSE-1 ram side

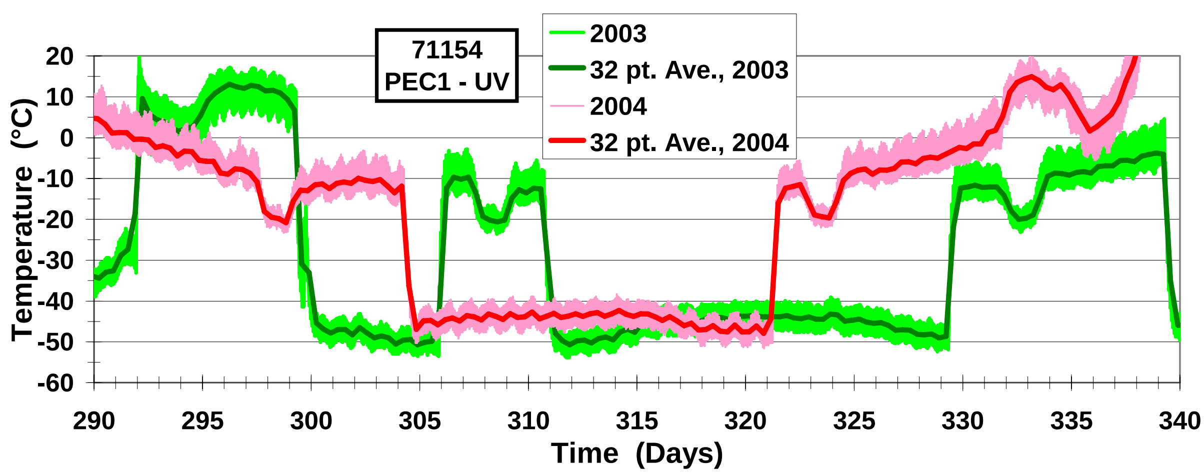

Figure 19 Temperature extremes recorded n datalogger 71154, MISSE-1 wake side

The almost 4 year duration of the experiments resulted in approximately 22800 thermal cycles for the MISSE specimens.

7.0 Micrometoeroid and Debris impacts

The surfaces of the experiments and the exterior surfaces of the PEC sides were inspected for impacts. A count was made of visible impacts plus impacts detectable with the use of a small magnifying glass. Estimates were made of the impact crater diameter. Table 5 is a summary of the range of impact sizes observed.

A preliminary examination found a total of 108 impacts visible on the 4 baseplates, each ~4 sq ft, for a total of 16 sq ft exposed surface area. There were another 16 impacts on the sides of the PECs. PEC 1 had 7 impacts and PEC 2 had 9 impacts. The exposure area was ~6 in x 24 in x 4 sides x 2 PECS, or an additional 8 sq ft of exposed surface area.

Subsequent examinations revised the number of impacts on the sample trays and baseplates upward to a total of 126. The distribution is surprisingly uniform (~equal number of impacts on both sides of each of the MISSE packages). A more comprehensive examination of the MISSE surfaces has been conducted, but only partial results are available. It is planned to compare the results with predictions of the ISS impact model once the detailed examination results are complete.

Size (diameter, mm)	Number of Impacts
0.1	1
0.2	8
0.3	45
0.4	2
0.5	30
0.75	8
1	7
1.2	1
1.5	2
2	2
3	2
Total	**108**

Table 5 Impact crater size distribution from initial inspection

8.0 Contamination

Visible inspections, followed by inspections using “black light” showed minimal to no contamination on the MISSE surfaces. The visible inspections of the exterior of the Passive Experiment Carriers (PECs) and the surfaces of the experiments and the baseplate supporting the individual showed visibly darkened areas only around the composite face-sheet, aluminum honeycomb core panel used to hold the Lockheed-Martin solar cell array. An image of the baseplate that held this experiment is shown in figure 20. The outgassing onto the baseplate was around the edges of this panel and localized within the immediate vicinity, 1-2 cm. The pattern is clearly visible in figure 20. No contamination was noted on specimens adjacent to this experiment.

Black light inspections revealed very minor amounts of organic contaminant on the exterior sides of the PECs, possibly due to handling. No organic-based molecular contamination was observed other that around the experiment previously mentioned.

The MISSE-1 and MISSE-2 hardware and specimens appeared to be "clean." It is possible that minute amounts of silicone-based contamination are present, but based on preliminary measurements, the levels of any such contamination are likely to be extremely low. Initial readings of optical properties of selected inorganic white paints indicate no change from pre-flight values, also suggesting the level of molecular contamination is quite low. Thin films of silicon-based contaminants were observed on sensitive optical surfaces.

Some particulate contamination was observed on certain specimens. Both silver oxide and polymer particulates were observed. No high quality images were obtained just prior to removal of the experiments from their deployment locations. For this reason, it is difficult to determine how the particulate distribution may have been modified during re-entry and re-pressurization.

In summary, the MISSE-1 and MISSE-2 experiments appear to have extremely low background levels of molecular contamination. This suggests that any measured changes in the properties of the material specimens will be due to intrinsic changes in the materials induced by the environmental exposures. There were specific locations where debris from mechanically failed, degraded specimens migrated onto the surface of other specimens. The extent of this particulate contamination distribution was minor.

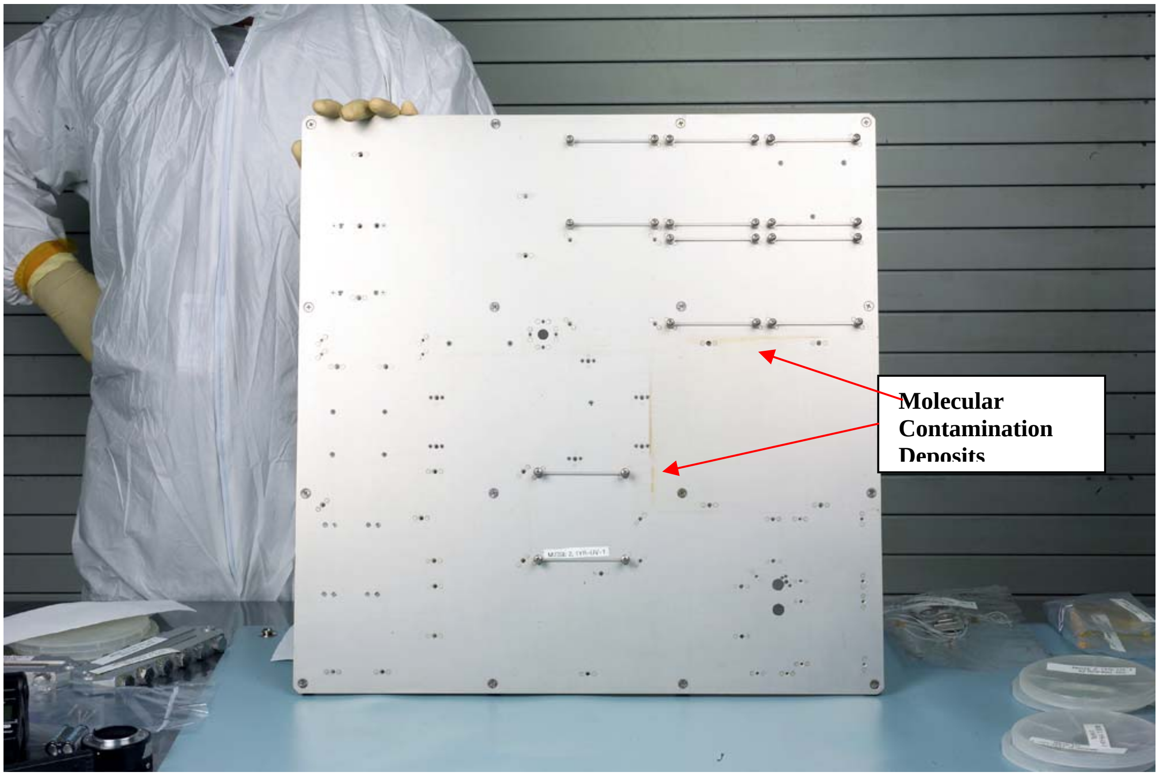

Figure 20 Baseplate for MISSE-2, UV-side, subsequent to removal of the experiments (NASA Image)

9.0 Particulate radiation levels (Dr. Eugene Normand)

Boeing and Space Systems/Loral each flew passive radiation detectors to measure total exposure dose.

Several radiation shielding experiments were incorporated into the MISSE experiments by the Boeing Radiation Effects Laboratory (BREL). Three distinct types of devices were used that respond to radiation differently, TLDs (thermoluminescent dosimeters), Charge-Coupled Devices (CCDs) and optocouplers. The TLDs respond to total ionizing dose, most of which is contributed to by the trapped electrons for locations with less than 100 mils of shielding. Most of the TLDs were removed from their experimental holders on Dec. 9, 2005 and they were counted with the BREL TLD reader about a week later. The standard calibration of the TLDs to obtain the readings in dose, rad (Si) was used.

TLDs from six experiments were retrieved, five from MISSE-1 and one from MISSE-2. The largest experiment is the BREB (Boeing Radiation Experimental Block), that contained 56 TLDs within an approximately 4.5”×2.5” block on MISSE-1. In all cases, four TLDs were located near each other, with the sets of four being shielded by different thicknesses of three materials, aluminum, composite 1 (black, 1.6 gm/cm^3) and composite 2 (yellow, 1.8 gm/cm^3); the shielding thicknesses varied from ~40-120 mils. Seven TLDs were loaded into experiment W3-5 on MISSE-1 which was shielded by 10 mils of tantalum.

Figure 21 shows the results of the post-flight TLD measurements. The dose values are plotted as a function of the shielding expressed as the areal density (thickness × density, units of gm/cm^2). Figure 21 also contains the measured dose values from a joint Canadian-Russian experiment, BION-11, that was located external to the Mir Space Station (G. MacKay et al, “Applications of MOSFET Dosimeters on MIR and BION Satellites,” IEEE Trans. Nuc. Sci., 44, 2048, 1997). MOSFET dosimeters were placed under varying thicknesses of thin shields in an orbit of ~52° inclination and 225-401 km, which is similar to that of Space Station. The BION-11 results were normalized to four years in orbit, to match the MISSE-1 and MISSE-2 exposure period.

Figure 21 also contains the calculated radiation dose as a function of aluminum thickness from a NASA guideline for Space Station (SSP30512, Rev. C, Space Station Ionizing Radiation Design Environment, NASA, JSC, June, 1994), separately showing the contribution from the trapped electrons (main source) and protons. The calculated doses are for 1 year of exposure. MISSE-1 was up for about four years. However, because of the MISSE-1 location near the airlock, it is clear that a significant portion of MISSE-1 was shielded by the Space Station structure. Since the agreement between the measured TLD doses (4 years) with the calculated doses (1 year) is relatively good, it appears that for MISSE-1, roughly 75% of the electrons were shielded out and not able to reach the TLD locations.

In March, 2006, two other sets of TLDs that had been located on other Boeing experimental trays, W2-15 and E4-36 on MISSE-1, were received. These data sets fill in

the data very nicely, especially W2-15, since it had minimal shielding (5 mils of Kapton, located on the trailing edge). There had been another experiment with 7 TLDs shielded by 5 mils of Kapton, (specimen E3-45), located on the leading edge of MISSE-1, where it received a high atomic oxygen fluence. No Kapton cover or TLD samples were found when it was returned. Because of its location, it is expected that the Kapton was completely eroded by the atomic oxygen. The Kapton-covered specimen at location W2-15 survived because it was on the nominal "trailing edge," and was exposed to a much smaller fluence of atomic oxygen.

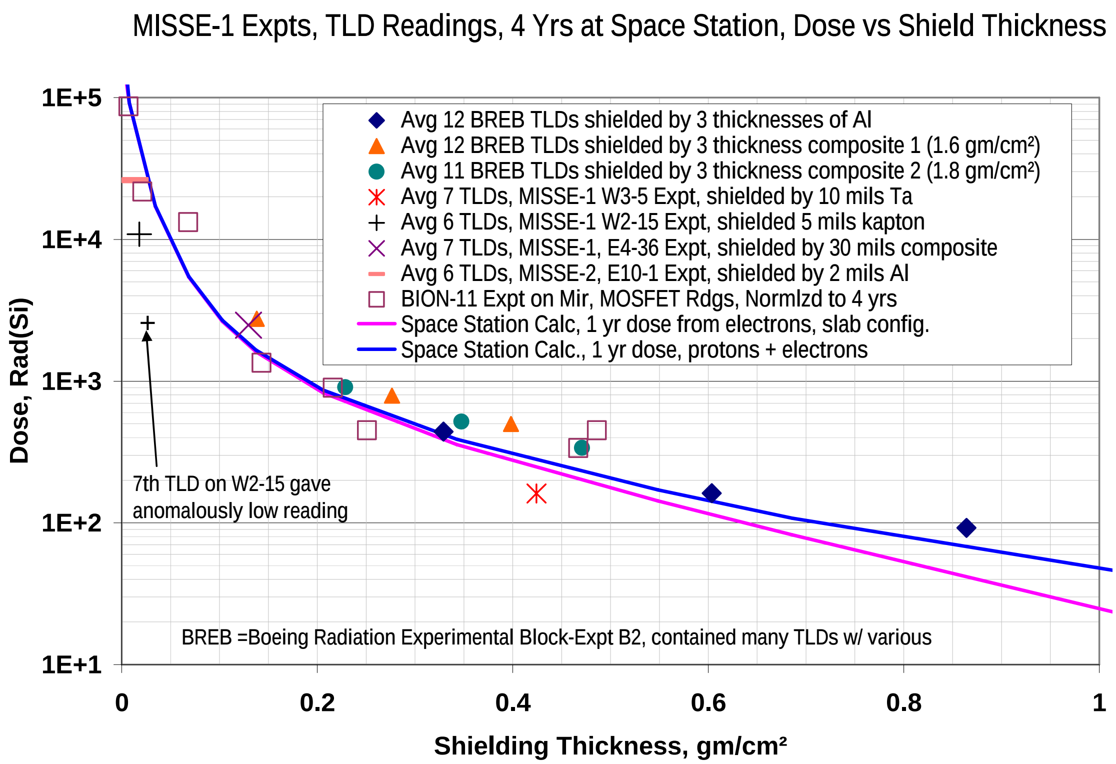

Figure 21 Dose from TLDs on MISSE-1 and MISSE-2 as Function of the Thickness of Aluminum

The W2-15 data point is very interesting because while six of the seven TLDs gave readings in the range of 7.5-14 E3 rads, for an average of 10.9 E3 rads, one TLD had an anomalously low reading of 2.8E3 rads. We believe that this anomalous TLD was influenced by a micrometeoroid strike. The Kapton covering the TLDs shows that this micrometeoroid hole was located right over the location of one of the TLDs and in fact it was over a TLD with Li-6. The impact on specimen W2-15 is shown in figure 22. The two types of TLDs used are LiF. Both Li-6 and Li-7 were selected for use, since the Li-6 TLDs would be sensitive to thermal neutrons. In all cases it appears that the contribution of the thermal neutrons to the dose deposited in the TLD is minimal, implying that the thermal neutron flux is too small relative to the electron flux to be measured by the TLDs.

The TLD with the anomalously low reading was one of the two Li-6 TLDs used, and that the micrometeoroid strike occurred over one of the two Li-6 TLDs. This implies that the micrometeoroid strike affected the TLD from the localized energy deposited which lead to a localized heating within the tiny well in which this TLD was housed. TLDs are read out by heating them up and measuring the resulting light emitted (luminescence). It is therefore presumed that right after the micrometeoroid strike, the energy stored in the TLD was partially discharged by the impact-induced heating. The TLDs were shaken up after they were returned to earth and it is not 100% certain which TLD was located underneath the micrometeoroid hole. However, the observations are highly suggestive. The well within which the TLD directly under the impact was housed, shows evidence of the impact event in the form of an apparent debris pattern. There is also some indication of the impact on the aluminum plate surface, right at the lip of the recessed area.

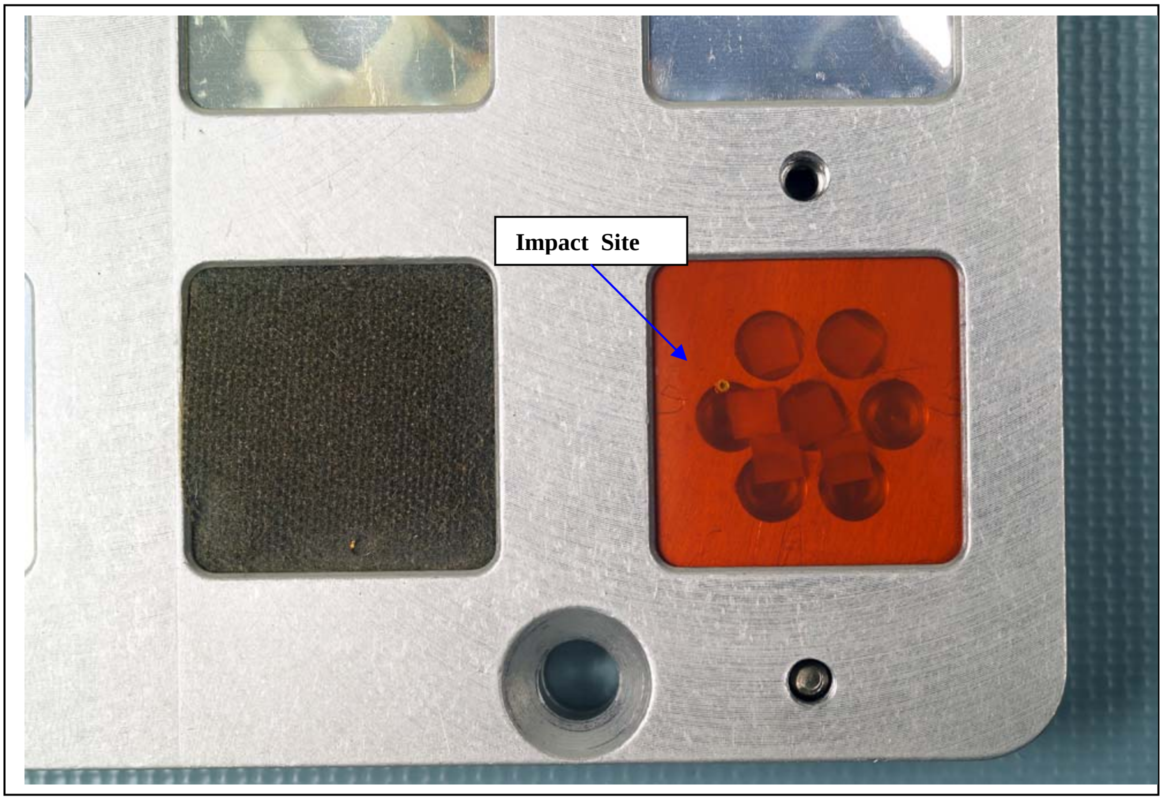

Figure 22 Close-up of specimen W2-15, showing the impact hole in the Kapton covering the TLD holder (NASA Image)

Figure 21 contains the one data point from MISSE-2. MISSE-2 was located at a different location on Space Station such that the Station structure should not have shielded MISSE-2 as much as it had MISSE-1. This seems to be shown in the figure since both the TLDs on W2-15 on MISSE-1 (5 mils of Kapton, 0.018 gm/cm²) and E10-1 on

MISSE-2 (2 mils of Al, 0.013 gm/cm^2) have a similar amount of shielding. Nevertheless, the W2-15 TLD readings, an average of 10.9 krad, is considerably lower than the E10-1 TLD readings, average of 26.1 krad. One of the reasons for this difference could be due to the diminished shielding that the Station structure provides MISSE-2 compared to MISSE-1. Additional TLD samples are on MISSE-3 and MISSE-4. Future readings from the TLDs on MISSE-3 and 4 will help to resolve differences in the effect of the structural shielding at the locations of the two MISSE flight experiments.

10.0 Summary

The MISSE-1 and MISSE-2 experiments were deployed at essentially the peak of the solar cycle. There were significant, frequent attitude changes in orientation between August 2001 and February 2003. Subsequent to the Columbia accident, these changes were less frequent, reflecting the different level of activity. Almost 100% of the atomic oxygen exposure to the nominal UV-side of the experiments occurred prior to March 2003. This means that for the final 28 months of the exposure period, the "UV-side" specimens experienced only the exposure conditions intended.

The range of altitudes over the 4 years was between 390 and 350 km. The flux rate of atomic oxygen was greatest during the early months of the mission. The decrease in atomic oxygen flux due to decreasing solar activity was somewhat mitigated by the slight decrease in altitude, with corresponding density increases, over the last 28 months of exposure.

11.0 Appendix A

Attitude of ISS as a function of time

Table A1 is an edited version of the ISS attitudes as a function of time, during the exposure period of MISSE-1 and -2. There were in excess of 2000 ISS attitude changes during the exposure period for the initial MISSE experiments. For the purposes of representing the attitudes, groups of similar orientations over contiguous time periods have been averaged into one. The averaged attitudes listed below were used to calculate the atomic oxygen and solar exposure levels for each surface of the MISSE-1 and MISSE-2 experiments. The yaw, pitch, and roll angles listed are in relation to the flight orientation of the ISS during the specific times. Details of the orientations can be found elsewhere. The purpose of the table is to give an indication of the time variation of the attitude of the experiment surfaces. Coupled with influences from the hardware within the line of sight of each experiment surface, exact exposure calculations become very time consuming and expensive. The estimates, correlated with the overall measured results, give environmental exposure levels to sufficient accuracy to evaluate materials performance.

Year	Month	Day	Hour	Minute	Second	Roll	Pitch	Yaw
2001	8	17	11	36	0.0	0.0	23	0
2001	8	17	13	48	0.0	0.0	239	0.0
2001	8	17	15	21	0.0	0.0	23	270.0
2001	8	19	12	10	0.0	0.0	23	0.0
2001	8	19	15	30	0.0	0.0	23	270.0
2001	8	20	15	17	0.0	0.0	23	0.0
2001	8	22	03	58	0.0	0.0	352.5	350.0
2001	8	22	06	19	0.0	0.0	0	180.0
2001	8	22	07	00	0.0	0.0	350.4	350.0
2001	8	23	07	41	0.0	1.5	355.2	359.1
2001	8	23	10	10	0.0	180.2	5.9	282.1
2001	8	27	12	16	0.0	0.0	352.5	350.0
2001	9	5	12	08	0.0	0.0	354.9	359.6
2001	9	10	20	40	0.0	0.0	352.4	350.0
2001	9	11	01	08	0.0	359.8	355.8	359.3
2001	9	13	21	45	0.0	0.0	352.4	350.0
2001	9	14	00	12	0.0	1.4	355.8	359.2
2001	9	14	02	09	0.0	238.2	317	135.7
2001	9	14	03	38	0.0	238.2	317	135.7
2001	9	15	00	00	0.0	0.0	352.4	350.0
2001	9	16	20	18	0.0	0.0	352.4	350.0
2001	9	16	20	23	0.0	0.0	352.4	350.0
2001	9	16	22	49	0.0	1.4	355.8	359.2
2001	9	17	01	15	0.0	230.5	324.1	133
2001	9	24	06	08	0.0	0.0	350.4	350.0
2001	9	26	15	06	0.0	0.0	354.8	179.4

2001	9	26	16	40	0.0	90.0	0	90.0
2001	10	6	08	36	0.0	0.0	354.8	179.4
2001	10	6	09	33	0.0	0.0	350.4	350.0
2001	10	19	09	07	0.0	1.3	354.9	359.2
2001	10	19	10	53	0.0	237.5	338.9	164.0
2001	10	19	11	28	0.0	237.5	338.9	164.0
2001	10	22	13	00	0.0	0.0	350.4	350.0
2001	10	22	13	30	0.0	0.0	352.6	359.6
2001	10	23	08	26	0.0	1.3	352.7	359.1
2001	10	23	11	01	0.0	236.3	32.9	110.3
2001	10	31	01	06	0.0	0.0	352.6	359.6
2001	10	31	01	35	0.0	270.0	0	270
2001	10	31	01	44	0.0			
2001	11	2	01	55	0.0	0.0	354.9	359.6
2001	11	2	05	17	0.0	181.3	5	0.8
2001	11	12	06	05	0.0	0.0	354.9	359.6
2001	11	13	05	22	0.0	0.0	352.4	350.0
2001	11	15	04	45	0.0	0.0	354.9	359.6
2001	11	22	14	05	0.0	0.0	350.4	350.0
2001	11	22	15	29	0.0	1.3	355	179.2
2001	11	22	16	08	0.0	0.0	0	180
2001	11	22	16	17	0.0			
2001	11	28	15	15	0.0	0.0	350.4	350.0
2001	11	28	17	29	0.0	1.3	354.2	359.1
2001	11	28	20	00	0.0	349.0	16	90.0
2001	12	5	17	19	0.0	0.0	352.4	350.0
2001	12	7	17	10	0.0	0.0	352.4	350.0
2001	12	7	20	58	0.0	0.00	0	0
2001	12	8	23	49	0.0	359.63	21.44	0.08
2001	12	9	01	44	0.0	0.0	21	270.
2001	12	9	14	36	0.0	359.63	21.44	0.08
2001	12	9	14	37	0.0	359.63	21.44	0.08
2001	12	9	16	19	0.0	0.00	239	0.00
2001	12	9	18	19	0.0	0.00	21	270.0
2001	12	11	15	47	0.0	359.63	21.44	0.08
2001	12	11	17	27	0.0	0.00	239	0.00
2001	12	11	19	32	0.0	0.00	21	270
2001	12	12	14	40	0.0	359.63	21.44	0.08
2001	12	12	16	29	0.0	0.00	5	180.0
2001	12	12	18	39	0.0	0.00	21	270.0
2001	12	12	19	04	0.0	0.00	21	0.00
2001	12	14	13	49	0.0	359.63	21.44	0.08
2001	12	14	16	04	0.0	0.00	21	270.0
2001	12	15	14	21	0.0	0.00	21	0.00
2001	12	15	15	17	0.0	0.00	239	0.00
2001	12	15	17	25	0.0	0.00	0	0.00
2001	12	17	10	00	0.0	0.00	352.99	350.00
2001	12	17	12	39	0.0	0.00	0	90.0
2001	12	18	12	10	0.0	0.00	352.99	350.00
2001	12	18	14	48	0.0	0.00	270	270.00

2001	12	19	06	30	0.0	0.00	352.99	350.00
2001	12	19	09	15	0.0	0.00	0	180.00
2001	12	19	10	40	0.0	0.00	352.99	350.00
2001	12	21	06	10	0.0	0.02	355.01	359.43
2001	12	21	08	56	0.0	180.00	0	180.00
2001	12	29	23	44	0.0	0.02	355.01	359.43
2001	12	30	01	16	0.0	1.45	355.39	269.19
2001	12	30	10	31	0.0	0.02	355.01	359.43
2001	12	30	12	04	0.0	1.45	355.39	269.19
2001	12	31	01	55	0.0	0.02	355.01	359.43
2001	12	31	03	28	0.0	1.45	355.39	269.19
2001	12	31	15	47	0.0	0.02	355.01	359.43
2001	12	31	17	20	0.0	1.45	355.39	269.19
2002	1	1	07	11	0.0	0.02	355.01	359.43
2002	1	1	08	43	0.0	1.45	355.39	269.19
2002	1	6	00	50	0.0	0.02	355.01	359.43
2002	1	6	03	32	0.0	267.0	315	54.7
2002	1	6	04	07	0.0	0.0	355	359.4
2002	1	12	17	10	0.0	0.0	353	350.0
2002	1	12	17	40	0.0	307.0	356.7	273.3
2002	1	30	14	45	0.0	0.0	353	350.0
2002	1	30	17	26	0.0	180.0	0	0
2002	2	21	10	07	0.0	0.0	353	350.0
2002	3	6	00	39	0.0	355.0	355	359.9
2002	3	6	04	40	0.0	0.0	357.9	359.5
2002	3	12	20	50	0.0	0.0	353	350.0
2002	3	13	01	07	0.0	0.0	357.9	359.5
2002	3	19	16	30	0.0	0.0	353	350.0
2002	3	19	17	48	0.0	0.0	0	0
2002	3	20	01	45	0.0	359.6	5.9	179.3
2002	3	21	23	20	0.0	0.0	351.3	350.0
2002	3	24	18	31	0.0	0.0	353.9	179.1
2002	3	24	20	55	0.0	1.3	354.1	179.1
2002	3	24	21	10	0.0	283.7	336.4	245.4
2002	3	24	22	00	0.0			
2002	4	5	15	45	0.0	0.0	354.9	179.2
2002	4	10	12	36	0.0	0.0	353	350.0
2002	4	10	16	27	0.0	0.00	0	0
2002	4	12	15	16	0.0	0.00	23	0.00
2002	4	12	15	36	0.0	0.00	348	270.0
2002	4	14	21	09	0.0	0.00	23	0.00
2002	4	14	22	49	0.0	0.00	60	180.0
2002	4	17	10	39	0.0	0.00	23	0.00
2002	4	17	12	24	0.0	0.00	6	180.0
2002	4	17	17	46	0.0	0.00	23	0.00
2002	4	20	07	35	0.0	0.00	0	0.00
2002	4	20	09	12	0.0	0.0	352.75	350
2002	4	20	09	55	0.0	271.38	342.09	298.46
2002	4	20	10	40	0.0			
2002	4	27	02	15	0.0	0.0	350.79	350.0

2002	4	27	05	32	0.0	1.86	352.69	359.37
2002	4	27	08	17	0.0	272.21	359.67	305.01
2002	5	4	23	06	0.0	0.00	350.79	350.0
2002	5	4	23	58	0.0	1.49	352.68	359.42
2002	5	5	00	27	0.0	0.00	90	0.00
2002	5	5	00	36	0.0			
2002	5	16	22	44	0.0	0.00	352.8	350.0
2002	6	7	13	35	0.0	0.0	354.4	179.3
2002	6	7	16	36	0.0	0.0	0	0.00
2002	6	10	20	12	0.0	0.00	23	0
2002	6	10	20	17	0.0	0.00	23.34	5.00
2002	6	10	21	57	0.0	0.00	60	180.0
2002	6	11	11	32	0.0	0.00	23	0.00
2002	6	11	14	17	0.0	0.00	23	270.0
2002	6	12	12	32	0.0	0.0	23	0
2002	6	12	14	07	0.0	0.00	60	180.0
2002	6	12	16	07	0.0	0.00	23	270.0
2002	6	13	11	07	0.0	352.0	23	357.0
2002	6	13	13	22	0.0	0.00	23	270.0
2002	6	14	12	03	0.0	0.00	23	0.00
2002	6	14	13	38	0.0	0.00	5	180.0
2002	6	14	15	38	0.0	0.00	23	270.0
2002	6	15	13	22	0.0	0.00	23	0.00
2002	6	25	08	22	0.0	0.00	0	0.00
2002	6	25	08	31	0.0			
2002	6	25	08	36	0.0	180.00	280	180.0
2002	6	26	5	40	0.0	0.8	349.8	350.0
2002	6	29	04	01	0.0	2.92	353.89	359.14
2002	6	29	06	25	0.0	174.83	14.94	268.66
2002	6	29	06	45	0.0			
2002	7	15	14	44	0.0	0.00	352.21	350.0
2002	8	1	16	17	0.0	0.0	354.3	179.3
2002	8	1	17	42	0.0	0.0	357.4	359.7
2002	8	9	18	49	0.0	0.0	354.3	179.3
2002	8	16	17	14	0.0	0.0	352.2	350.0
2002	8	23	03	17	0.0	0.0	354.3	359.4
2002	8	26	14	32	0.0	0.0	352.2	350.0
2002	9	6	20	01	0.0	0.0	354.3	359.4
2002	9	11	20	35	0.0	0.0	352.2	350.0
2002	9	11	22	33	0.0	2.9	354.8	359.2
2002	9	12	01	19	0.0	4.0	357.4	359.7
2002	9	20	14	10	0.0	0.0	352.2	350.0
2002	9	24	04	12	0.0	355.0	350.5	350.0
2002	9	24	04	40	0.0	356.0	355	0
2002	9	24	12	00	0.0	355.0	350.5	350.0
2002	9	24	13	20	0.0	2.80	354.8	359.2
2002	9	24	13	55	0.0	72.9	0	180.0
2002	9	24	14	04	0.0	38.0	0	180.0
2002	9	24	16	33	0.0	3.4	353.4	179.1
2002	9	24	17	06	0.0	0.0	90	180.0

2002	9	27	15	10	0.0	355.0	350.5	350.0
2002	9	27	16	40	0.0	3.4	353.4	359.1
2002	9	27	20	28	0.0	304.9	327.9	357.1
2002	9	29	13	30	0.0	355.0	350.5	350.0
2002	9	29	14	50	0.0	3.4	353.4	359.1
2002	9	29	17	25	0.0	285.0	10	0
2002	10	8	11	10	0.0	0.0	352.2	350.0
2002	10	8	14	50	0.0	3.27	354.33	359.23
2002	10	9	13	58	0.0	0.00	352.2	350.0
2002	10	9	15	28	0.0	0.0	0	0
2002	10	9	16	00	0.0	0.0	0	0
2002	10	10	21	45	0.0	0.0	23.9	0
2002	10	12	10	12	0.0	354.6	24.25	358.12
2002	10	12	12	02	0.0	0.00	5	180.0
2002	10	13	12	00	0.0	354.61	24.25	358.12
2002	10	13	14	40	0.0	0.00	24	270.0
2002	10	14	10	41	0.0	354.61	24.25	358.12
2002	10	14	11	57	0.0	0.00	5	180.0
2002	10	16	12	30	0.0	354.61	24.25	358.12
2002	10	16	13	54	0.0	0.00	0	0.00
2002	10	16	15	50	0.0	0.00	351.14	347.00
2002	11	1	02	09	0.0	0.4	351.41	354.97
2002	11	1	05	20	0.0	160.01	340.07	255.90
2002	11	6	23	10	0.0	0.38	351.41	354.97
2002	11	7	05	03	0.0	358.41	357.79	355.78
2002	11	9	16	55	0.0	0.00	351.14	347.00
2002	11	9	20	01	0.0	347.84	351.04	357.4
2002	11	9	20	49	0.0	180.00	87.3	180.0
2002	11	25	20	00	0.0	0.00	351.14	347.0
2002	11	25	21	45	0.0	0.0	0	0
2002	11	26	19	00	0.0	355.57	22.86	358.77
2002	11	27	16	30	0.0	1.35	22.54	0.83
2002	11	27	17	57	0.0	0.00	4	180
2002	11	29	16	16	0.0	1.35	22.54	0.83
2002	11	29	17	49	0.0	0.00	239	0.00
2002	11	29	22	44	0.0	1.35	22.54	0.83
2002	11	30	01	29	0.0	0.0	22.54	270
2002	12	2	19	15	0.0	0.00	22.74	5.00
2002	12	2	19	35	0.0	1.35	22.54	0.83
2002	12	2	20	50	0.0	0.00	0	0.00
2002	12	14	09	47	0.0	0.00	350.9	350.0
2002	12	21	16	10	0.0	359.96	351.19	0.52
2002	12	26	05	49	0.0	1.84	351.33	270.11
2003	1	8	01	54	0.0	359.96	351.19	0.52
2003	1	16	00	00	0.0	0.00	350.9	350.0
2003	1	22	08	28	0.0	359.96	351.22	180.5
2003	1	22	11	33	0.0	180.00	8.5	90.60
2003	1	25	04	50	0.0	359.96	351.22	180.5
2003	1	27	19	07	0.0	0.00	350.9	350.0
2003	1	27	19	10	0.0	215.9	348.905	189.293

2003	2	1	14	00	0.0	0.000	350.9	350.0
2003	2	1	18	40	0.0	356.74	351.64	1.14
2003	2	1	19	25	0.0	270.00	89.42	270.0
2003	2	4	11	10	0.0	0.00	350.9	350.0
2003	2	4	12	35	0.0	357.64	350.57	359.81
2003	2	4	15	08	0.0	48.22	354.25	352.70
2003	2	8	12	15	0.0	0.00	350.9	350.0
2003	2	8	15	50	0.0	357.62	352.05	359.79
2003	2	11	08	50	0.0	0.00	350.9	350.0
2003	2	11	10	37	0.0	357.62	352.05	359.79
2003	2	11	12	02	0.0	0.00	375.2	359.62
2003	2	17	08	25	0.0	359.96	351.19	0.52
2003	2	17	08	42	0.0	142.26	328.04	164.63
2003	3	13	21	28	0.0	359.96	351.19	0.52
2003	3	13	23	45	0.0	0.00	356.4	0.40
2003	4	4	10	30	0.0	359.96	351.22	180.5
2003	4	4	11	40	0.0	357.62	352.05	359.79
2003	4	7	11	30	0.0	0.00	356.4	0.40
2003	4	7	13	20	0.0	357.62	352.05	359.79
2003	4	28	00	30	0	0.00	350.9	350.0
2003	4	28	00	33	0	+0.5	+351.2	+360.0
2003	4	28	03	33	0	+359.8	+352.1	+357.6
2003	4	28	06	09	0	+185.6	+38.9	+132.6
2003	5	4	19	00	0	+350.0	+350.6	+0.0
2003	5	4	22	10	0	+359.8	+351.7	+357.5
2003	5	4	22	48	0	+358.6	+81.7	+356.1
2003	5	5	00	45	0	+359.7	+353.8	+358.0
2003	5	5	01	17	0	+200.6	+271.6	+159.4
2003	5	12	17	18	0	+350.0	+352.8	+0.0
2003	5	19	03	16	0	+180.5	+353.1	+360.0
2003	5	28	04	37	0	+90.2	+349.2	+356.8
2003	5	31	14	10	0	-179.5	-6.9	+0.0
2003	5	31	14	20	0	+180.5	+353.1	+360.0
2003	5	31	15	30	0	+359.7	+353.8	+358.0
2003	5	31	17	03	0	+0.0	+0.0	+0.0
2003	6	8	03	44	0	+180.5	+353.1	+360.0
2003	6	12	07	40	0	+350.0	+352.8	+0.0
2003	6	12	09	02	0	+359.7	+353.8	+358.0
2003	6	12	11	37	0	+227.0	+19.6	+107.4
2003	6	13	11	27	0	+350.0	+350.6	+0.0
2003	7	1	02	52	0	+0.5	+351.0	+360.0
2003	7	12	18	41	0	+350.0	+350.6	+0.0
2003	7	13	05	37	0	+90.2	+351.4	+356.8
2003	7	17	03	28	0	+180.5	+351.0	+360.0
2003	7	30	19	28	0	+90.2	+351.4	+356.8
2003	8	3	10	10	0	+180.5	+351.0	+360.0
2003	8	3	16	15	0	+179.5	+359.7	+359.8
2003	8	6	00	37	0	+180.5	+351.0	+360.0
2003	8	10	15	18	0	+350.0	+350.6	+0.0
2003	8	21	17	20	0	+0.5	+351.0	+360.0

2003	8	28	20	38	0	+350.0	+350.6	+0.0
2003	8	28	22	53	0	+359.8	+351.7	+357.5
2003	8	31	23	45	0	+350.0	+346.9	+0.0
2003	9	1	01	32	0	+359.8	+350.6	+357.6
2003	9	1	03	50	0	+337.8	+31.8	+311.8
2003	9	5	15	58	0	+350.0	+350.6	+0.0
2003	9	5	19	09	0	+359.8	+352.0	+357.6
2003	9	5	20	00	0	+181.7	+278.0	+175.9
2003	9	5	22	09	0	+359.7	+353.8	+357.9
2003	9	5	22	35	0	+343.0	+88.1	+343.1
2003	9	6	13	02	0	+350.0	+352.8	+0.0
2003	9	17	17	58	0	+180.5	+353.1	+360.0
2003	9	23	23	06	0	+90.2	+349.2	+356.8
2003	10	1	10	02	0	+180.5	+353.1	+360.0
2003	10	1	11	35	0	+359.7	+353.8	+357.9
2003	10	1	13	23	0	+0.4	+356.4	+0.0
2003	10	7	19	32	0	+350.0	+352.8	+0.0
2003	10	20	05	00	0	+0.5	+353.1	+360.0
2003	10	20	07	36	0	+178.3	+9.7	+79.9
2003	10	27	14	45	0	+270.1	+351.1	+1.8
2003	10	27	22	44	0	+0.5	+351.0	+360.0
2003	10	27	23	22	0	+278.3	+359.8	+267.5
2003	10	28	01	20	0	+359.8	+351.9	+357.6
2003	10	28	01	54	0	+270.2	+0.6	+93.9
2003	11	3	04	28	0	+0.5	+351.0	+360.0
2003	11	8	01	21	0	+350.0	+350.6	+0.0
2003	11	11	14	10	0	+180.5	+351.0	+360.0
2003	11	11	21	15	0	+179.5	+0.3	+359.8
2003	11	26	15	56	0	+180.5	+351.0	+360.0
2003	12	6	15	10	0	+350.0	+350.6	+0.0
2003	12	8	14	35	0	+0.5	+351.0	+360.0
2003	12	26	15	15	0	+270.1	+351.1	+1.8
2004	1	1	23	00	0	+0.5	+351.0	+0.0
2004	1	8	16	54	0	+350.0	+350.6	+0.0
2004	1	8	18	15	0	+359.8	+351.9	+357.6
2004	1	8	20	10	0	+0.4	+356.4	+0.0
2004	1	8	22	07	0	+359.8	+351.9	+357.6
2004	1	24	14	17	0	+180.5	+351.0	+360.0
2004	1	24	17	34	0	+359.8	+351.9	+357.6
2004	1	28	06	35	0	+350.0	+350.6	+0.0
2004	1	28	08	41	0	+359.8	+351.9	+357.6
2004	1	31	09	37	0	+350.0	+347.4	+0.0
2004	1	31	13	22	0	+359.8	+350.7	+357.6
2004	2	5	09	11	0	+0.5	+351.0	+360.0
2004	2	5	11	02	0	+359.8	+352.1	+357.6
2004	2	5	12	45	0	+354.7	+351.9	+358.3
2004	2	21	19	11	0	+270.1	+351.1	+1.8
2004	2	25	19	36	0	+0.5	+351.0	+360.0
2004	2	26	18	50	0	+350.0	+350.6	+0.0
2004	2	26	21	16	0	+359.8	+352.1	+357.6

2004	3	2	00	28	0	+350.0	+350.6	+0.0
2004	3	3	00	09	0	+359.8	+352.1	+357.6
2004	3	3	01	25	0	+179.8	+4.1	+357.6
2004	3	5	16	58	0	+180.5	+351.0	+360.0
2004	3	5	23	33	0	+179.5	+0.0	+359.8
2004	3	28	02	13	0	+180.5	+351.0	+360.0
2004	4	1	18	01	0	+350.0	+350.6	+0.0
2004	4	1	21	12	0	+359.8	+352.1	+357.6
2004	4	2	08	32	0	+350.0	+350.6	+0.0
2004	4	2	09	05	0	+359.5	+296.6	+358.0
2004	4	21	23	55	0	+0.5	+351.0	+360.0
2004	4	22	02	40	0	+359.8	+352.1	+357.6
2004	4	22	05	23	0	+221.2	+286.0	+350.3
2004	4	22	06	10	0	+350.0	+350.6	+0.0
2004	4	29	17	35	0	+350.0	+350.6	+0.0
2004	4	29	20	19	0	+359.8	+351.8	+357.5
2004	4	29	20	57	0	+358.5	+81.8	+355.9
2004	4	29	22	45	0	+359.6	+353.9	+357.9
2004	4	29	23	25	0	+4.8	+83.2	+184.8
2004	4	29	23	56	0	+89.6	+353.9	+357.9
2004	5	5	14	54	0	+350.0	+352.8	+0.0
2004	5	18	15	10	0	+90.2	+353.3	+356.3
2004	5	18	17	02	0	+348.6	+0.4	+270.0
2004	5	18	18	19	0	+89.6	+353.9	+357.9
2004	5	24	08	46	0	+180.5	+353.1	+360.0
2004	5	24	09	24	0	+179.6	+353.9	+357.9
2004	5	27	11	42	0	+180.5	+353.1	+360.0
2004	5	27	14	04	0	+224.7	+7.9	+197.6
2004	6	3	13	47	0	+350.0	+352.8	+0.0
2004	7	3	03	20	0	+0.5	+353.1	+360.0
2004	7	17	01	25	0	+90.2	+353.3	+356.3
2004	7	26	13	00	0	+180.5	+353.1	+360.0
2004	8	3	15	24	0	+350.0	+352.8	+0.0
2004	8	14	01	22	0	+0.8	+351.9	+359.9
2004	8	14	02	47	0	+359.6	+353.1	+357.9
2004	8	14	05	10	0	+329.2	+24.8	+355.2
2004	8	18	23	41	0	+0.5	+353.1	+360.0
2004	8	26	01	05	0	+350.0	+352.8	+0.0
2004	9	2	01	38	0	+180.5	+353.1	+360.0
2004	9	4	02	35	0	+350.0	+352.8	+0.0
2004	9	17	15	01	0	+180.5	+353.1	+360.0
2004	9	23	11	30	0	+350.0	+352.8	+0.0
2004	9	23	12	20	0	+0.4	+356.4	+0.0
2004	9	30	13	32	0	+350.0	+352.8	+0.0
2004	10	16	00	55	0	+0.5	+353.1	+360.0
2004	10	16	02	11	0	+359.6	+354.0	+358.0
2004	10	16	04	27	0	+227.4	+321.1	+145.6
2004	10	23	17	49	0	+350.0	+350.6	+0.0
2004	10	23	20	36	0	+359.8	+351.9	+357.5
2004	10	23	21	14	0	+0.0	+90.0	+0.0

2004	10	23	23	22	0	+359.8	+352.1	+357.6
2004	10	23	23	48	0	+0.0	+285.0	+0.0
2004	10	24	00	15	0	+0.0	+30.0	+0.0
2004	10	31	13	14	0	+350.0	+350.6	+0.0
2004	10	31	19	50	0	+179.5	+1.2	+359.8
2004	11	17	11	51	0	+180.5	+351.0	+360.0
2004	11	17	14	26	0	+15.4	+356.4	+0.0
2004	11	27	23	47	0	+350.0	+350.6	+0.0
2004	11	29	07	46	0	+268.5	+351.3	+0.2
2004	11	29	09	37	0	+181.6	+326.5	+222.1
2004	11	29	10	14	0	+181.6	+326.5	+222.1
2004	12	13	14	43	0	+269.0	+353.2	+360.0
2004	12	21	19	44	0	+0.5	+353.1	+360.0
2004	12	22	19	42	0	+350.0	+352.8	+0.0
2004	12	22	22	54	0	+356.9	+83.2	+354.8
2004	12	25	21	27	0	+350.0	+349.6	+0.0
2004	12	26	00	07	0	+55.5	+335.9	+231.7
2005	1	11	13	34	0	+180.5	+353.1	+360.0
2005	1	26	18	43	0	+350.0	+352.8	+0.0
2005	2	8	15	47	0	+269.0	+353.2	+0.0
2005	2	15	23	31	0	+0.5	+353.1	+360.0
2005	2	16	00	10	0	+359.7	+354.0	+358.0
2005	2	16	01	34	0	+0.4	+356.4	+0.0
2005	2	22	15	55	0	+350.0	+352.8	+0.0
2005	2	27	13	45	0	+180.5	+353.1	+360.0
2005	2	27	16	11	0	+359.7	+354.0	+358.0
2005	2	27	19	10	0	+357.4	+83.1	+355.1
2005	3	2	18	13	0	+180.8	+351.9	+359.9
2005	3	2	20	20	0	+100.3	+333.5	+230.7
2005	3	5	20	19	0	+180.5	+353.1	+360.0
2005	3	5	20	36	0	+180.5	+353.1	+180.5
2005	3	17	02	07	0	+180.5	+353.1	+360.0
2005	3	25	08	35	0	+350.0	+352.8	+0.0
2005	3	25	10	11	0	+0.4	+356.4	+0.0
2005	4	24	17	50	0	+350.0	+352.8	+0.0
2005	4	24	18	50	0	+358.8	+81.8	+356.1
2005	4	24	21	00	0	+359.8	+352.0	+357.5
2005	4	24	21	22	0	+0.0	+280.0	+0.0
2005	4	24	21	47	0	+0.0	+30.0	+0.0
2005	4	24	21	52	0	+0.0	+350.0	+0.0
2005	5	11	12	12	0	+88.4	+352.2	+354.3
2005	6	18	22	37	0	+359.8	+352.0	+357.5
2005	6	19	01	04	0	+296.0	+6.9	+98.8
2005	6	22	10	10	0	+350.0	+350.9	+0.0
2005	6	29	18	50	0	+88.4	+352.2	+356.0
2005	6	29	20	13	0	+356.4	+359.6	+90.0
2005	6	29	21	15	0	+173.4	+80.8	+220.8
2005	7	6	12	45	0	+88.4	+352.2	+356.0
2005	7	6	15	10	0	+0.4	+356.4	+0.0
2005	7	9	13	09	0	+88.4	+352.2	+356.0

	7	19	09	01	0	+350.0	+350.9	+0.0
2005	7	19	11	21	0	+99.0	+22.0	+314.0
2005	7	28	08	40	0	+350.0	+352.7	+0.0
2005	7	28	11	43	0	+0.0	+0.0	+0.0
2005	7	30	10	40	0	+177.4	+24.6	+359.6
2005	7	30	16	37	0	+192.0	+25.0	+345.0
2005	7	31	06	24	0	+177.4	+24.6	+359.6
2005	7	31	08	52	0	+205.0	+25.0	2005
2005	7	31	09	07	0	+177.4	+24.6	+359.6

Table A1 Attitude of ISS with respect to the coordinate system of whatever orientation ISS was in at the time (The orientation of ISS changed periodically with respect to the direction of motion.)

12.0 Appendix B

Post-Flight disassembly of MISSE-1 & -2

The MISSE Passive Experiment Carriers (PECs) were removed from the Space Shuttle at Kennedy Space Center several weeks after the hardware was returned to ground. The PECs were bagged, placed in a protective container, shipped to NASA LaRC, and brought into a clean room The PEC outer edges were examined for meteoroid and debris impact sites, and the data loggers were accessed and the time-temperature data recovered. Investigators were invited to come to NASA LaRC and inspect their specimens when the PECs were first opened. Figure X below shows the opening of MISSE-2 in the clean room. A comprehensive series of images were recorded during the inspection and disassembly of these experiments. This appendix shows a few representative images from that process. A CD containing much more complete set is available from NASA.

All the images shown in this appendix were provided by NASA.

Figure B1 The initial opening of MISSE-2 in the NASA LaRC clean room

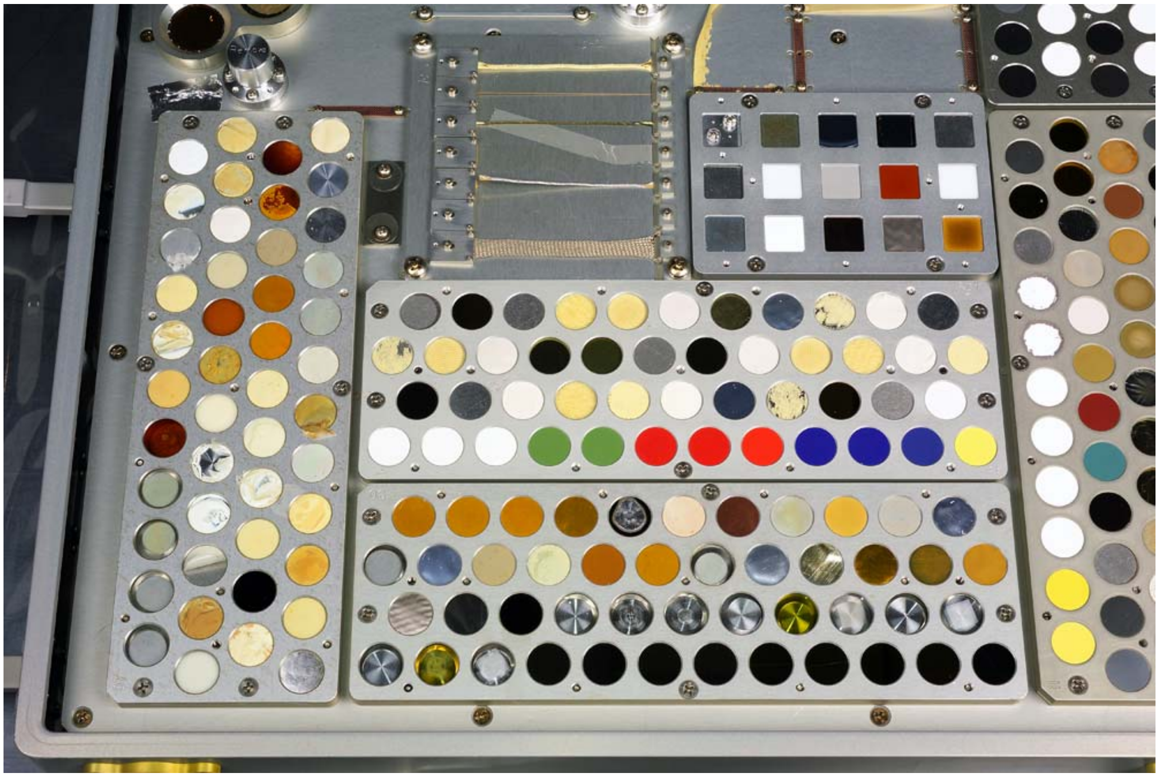

Figure B2 A portion of the "ram" side of MISSE-2

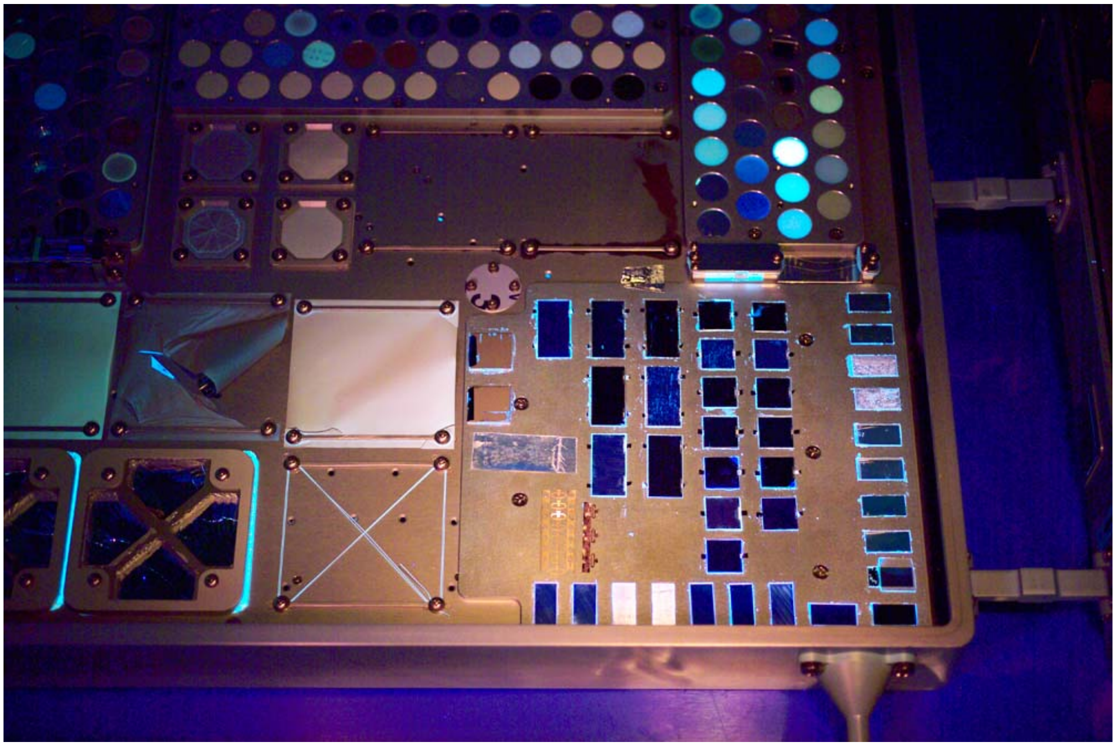

Figure B3 Black-light inspection of "wake" side of MISSE-2. Fluorescent materials are clearly evident, but very little contamination

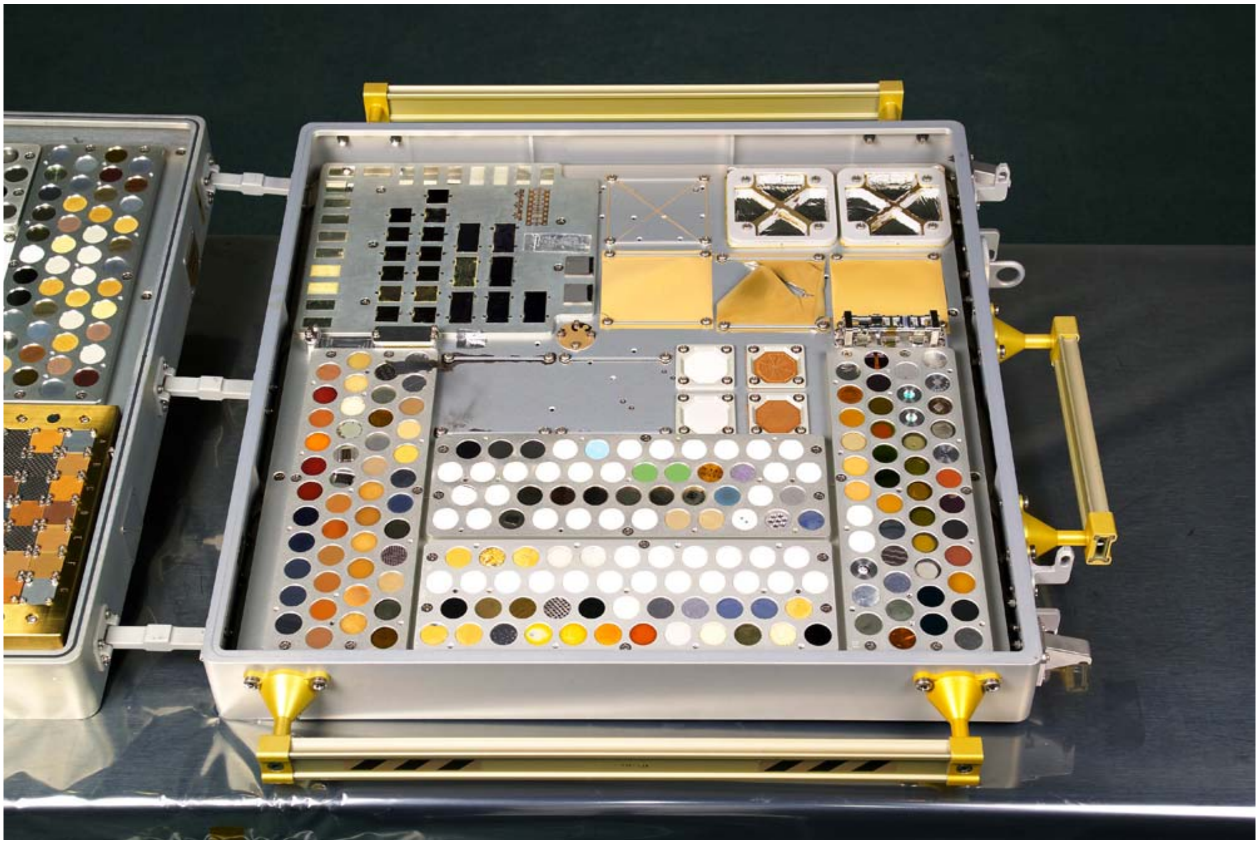

Figure B4 "ram" side of MISSE-1

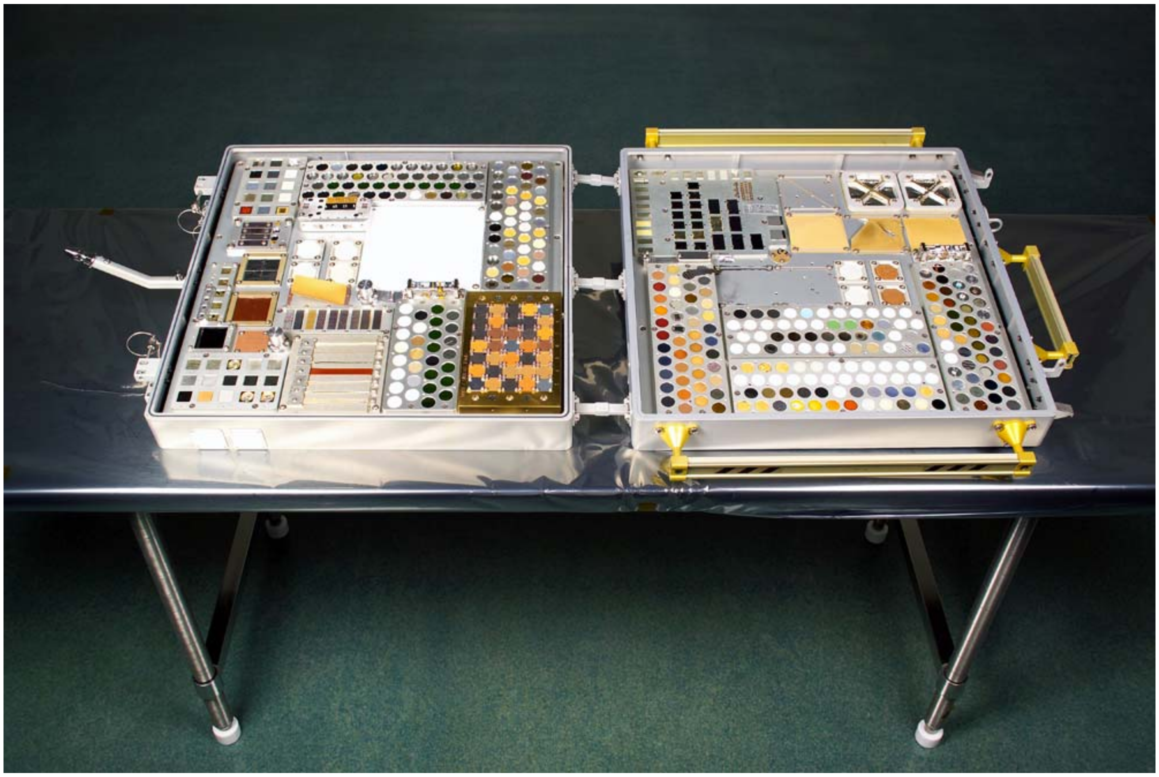

Figure B5 MISSE-1, post-flight, just prior to disassembly of individual experiments

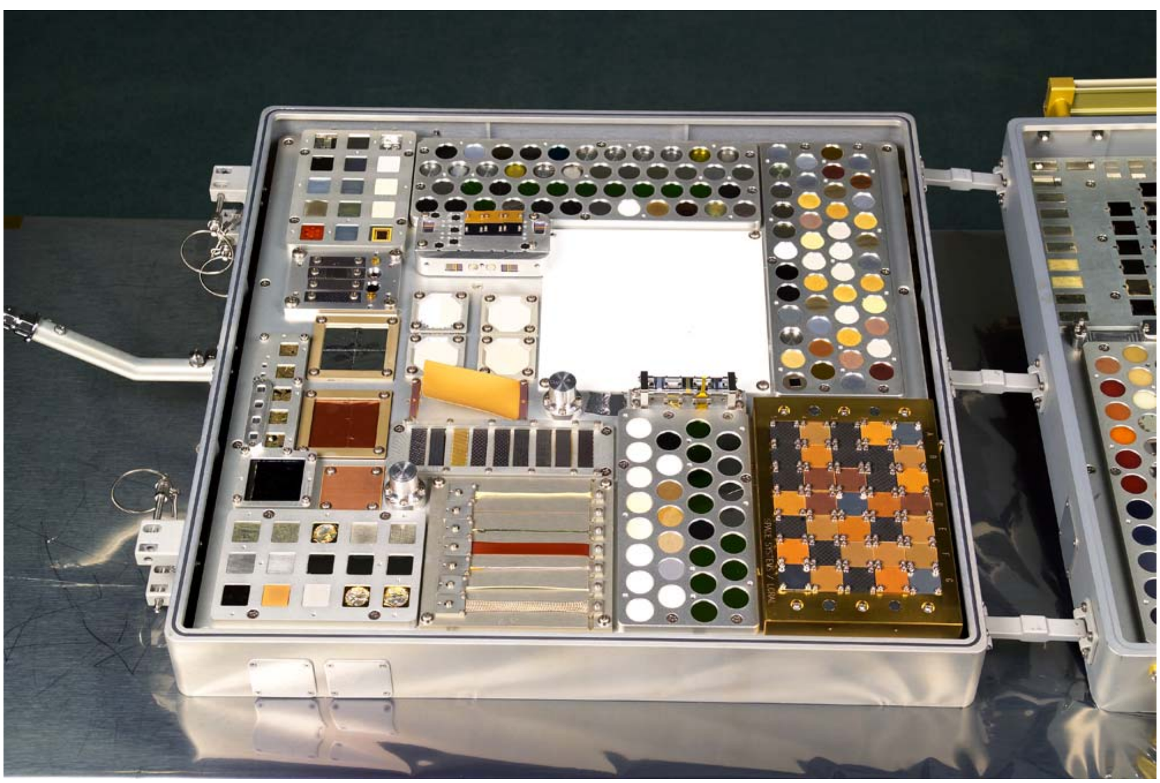

Figure B6 "wake" side of MISSE-1

Figure B7 "Wake" side of MISSE-2

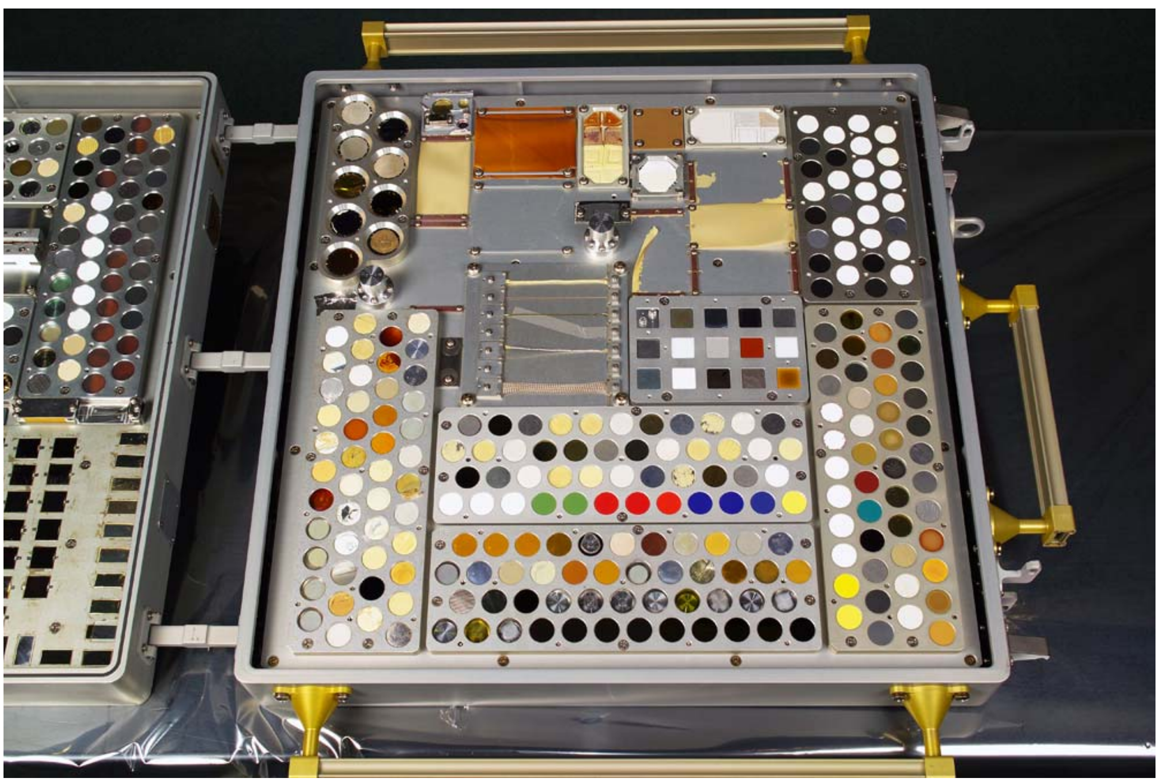

Figure B8 "Ram" side of MISSE-2